

COMMERCIAL MUSHROOM PRODUCTION



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COMMERCIAL MUSHROOM PRODUCTION

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This publication is intended to outline some of the basic practices used in commercial button and oyster mushroom production. It should be of particular use to new growers and also provide a practical review for those with experience. Some specific guidelines and explanations of certain cultural practices are included.

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I. CULTIVATION OF BUTTON MUSHROOMS

Since edible mushrooms are often found growing wild, the layman assumes that commercial production is a simple process. However, growing cultivated mushrooms requires a rigidly controlled environment with exacting attention to temperature, humidity, CO₂ and ventilation, as well as monitoring for insects and diseases.

During the lifetime of Louis XIV of France (1638-1715) the art and science of mushroom growing was born. By 1800 underground caves in Paris were commonly used for mushroom growing. Around 1885, greenhouse growers were growing mushrooms under benches in Chester and Philadelphia counties of Pennsylvania. Mushroom cultivation in Canada goes back to 1912 when mushrooms were experimentally grown under greenhouse benches in eastern Canada.

In less than 75 years commercial production of mushrooms in Canada has grown to 48.5 million kilograms (kg) (1985 statistics, preliminary) at a farm gate value of \$132.7 million. Mushrooms are the third most valuable vegetable crop in Canada and second in Ontario, and accounted for 19% of the farm value of commercial vegetable crops in Ontario during 1985.

Mushrooms are produced in all areas of Canada. In 1985 Ontario was the largest producer followed by British Columbia, the Prairie Provinces and the Maritimes (includes Quebec).

In 1964 the first survey was undertaken to obtain data on Canadian mushroom production. The production of mushrooms has increased from 8.3 million kg (18.3 million lbs.) in 1964 to 48.5 million kg (106.9 million lbs.) in 1985, an increase of 500%. This phenomenal growth in mushroom production has developed as a function of several factors. The amount of production surface available for mushroom cultivation has increased to slightly more than 633,144 m² (6.8 million sq. ft.), an increase of about 66% since 1964. The average number of crops per production room has increased from slightly more than 2 to 4 per annum. The average yield per square metre of production surface in 1964 was 8.8 kg (1.8 lb./sq. ft.) whereas in 1985 the average yield was 19.1 kg/m² (3.9 lb./sq. ft.) per crop (an increase of more than 100%). In the past 20 years, there has also been an increase of about 40% in the number of mushroom farm owners.

Since 1964, total imports of mushrooms (both fresh and canned) have grown from less than 1.4 million kg (3 million lbs.) to 24.5 million kg (53.8 million lbs.) in 1984. Fresh mushrooms accounted for 12% of Canadian mushroom imports in 1984. Ninety-eight percent of fresh imports came from the United States. Imports of mushrooms from Asia accounted for 77% of the canned imports with the People's Republic of China being the principal contributor during 1984.

All domestic production was consumed in Canada with the exception of a few thousand kilograms of fresh mushrooms being exported to Japan from Vancouver. Apparent disappearance of mushrooms in Canada has grown from 10.5 million kg (23.1 million lbs.) in 1964 to 65.6 million kg (144.4 million lbs.) in 1984. Data from 1960 to 1980 indicate that Canada's average rate of increase in consumption per person per year was 84 grams, ranking second in rate of increase to West Germany at 134 grams. Canadians are consuming about 5% of the world's production of mushrooms.

The average price received by growers has gradually increased from \$0.915/kg (0.416/lb.) in 1966 to \$2.73/kg (1.24/lb.) in 1985. The proportion of product sold as fresh

mushrooms has increased from 43% in 1965 to 71% in 1985. Average price for fresh market mushrooms in 1985 was \$3.19/kg (1.45/lb.) with processing mushrooms averaging \$1.60/kg (0.73/lb.).

Mushrooms have long been considered a delicacy. Of the many edible fleshy fungi, *Agaricus brunnescens* (*bisporus*) has principal commercial significance in Ontario. However, at least 20 species of mushrooms have been cultured in protected environments, e.g. *Lentinus edodes* (Shiitake), *Pleurotus* sp. (Oyster, Abalone, Phoenix, Trumpet), *Flammulina velutipes* (Velvet stem), *Volvariella volvacea* (Straw). Ontario growers are experimentally culturing *Pleurotus ostreatus* with a 1985 production level of about 1.5 metric tonnes per week. *Lentinus edodes* is also under cultivation but on a smaller scale.

Mushrooms contain about 90% water, 3% protein, 4% carbohydrates, 0.3% fat and 1% vitamins and minerals on a fresh weight basis, with a calorie content of about 30 per 100 grams.

Terminology Used in Commercial Production

Mushrooms are fungi and lack chlorophyll. They cannot produce their own food and depend entirely on organic materials for nutrition. The nutrients are provided by a medium called "compost".

In many cases, horse manure is the basic material for compost. Preparation of the compost occurs outside on a concrete slab often protected from extreme weather conditions by a roof. The horse manure enriched with nitrogen-containing compounds is set up in piles (Phase I) and turned regularly by special equipment.

The Phase II process or cook-out period takes place under controlled environmental conditions. The compost is filled into the beds or trays of mushroom house, and parasitic organisms such as pathogenic fungi, bacteria, virus-infected spores, nematodes, insect larvae, etc., are killed by a pasteurization procedure. After this treatment the compost is conditioned at temperatures of 50 to 55°C. The total Phase II process normally takes between one and two weeks.

When the cook-out is finished, the beds or trays are cooled down and "spawn" is added to the compost. Spawn consists of cereal grains which have been inoculated with mycelium of the mushroom fungus. The period during which spawn grows throughout the compost is called "spawn run".

After the mycelia has colonized the compost in two to three weeks, a "casing layer" is added to the surface of the compost. The major casing material in Canada is peat moss to which lime has been added.

The mycelia will grow through the casing soil and will form small "pins" (primordia) on top of the casing as a result of altered fungal physiology induced by changing the environmental conditions. These pins will develop into mushrooms.

Mushrooms grow in "flushes" or "breaks" about 7 to 11 days apart, depending mainly on temperature. Commercial growers harvest over a period of 30 to 60 days calculated from the date of the first pick. The first two flushes usually produce as much as 50% of the total yield with daily picks tapering off towards the end of the cycle.

The production cycle can be summarized as:

Phase I composting — two to three weeks

Phase II composting or cook-out — one to two weeks

Spawn run — two weeks

Casing to first pick — three weeks

Harvesting — four to nine weeks

Economic Considerations

There are two major reasons for the small number of commercial mushroom growers. The first is the general lack of knowledge of the techniques of mushroom growing. The second is the relatively large capital investment required to establish a viable mushroom farm. The average size of an Ontario mushroom farm is over 6000 m²; 2000 m² of production area is considered the economic threshold for a family operation. Smaller farms exist but cannot be considered self-sustaining. Depending on the degree of sophistication that the grower incorporates into the growing facility, a cost of \$150 to \$500/m² of production surface can be allocated to the construction of a complete mushroom farm. This would include machinery and climate control equipment.

Availability of raw materials such as horse manure, hay and straw must be considered before establishing a new mushroom farm. These materials are bulky and haulage costs can be significant. Proximity to the major market is a second important criterion for site selection. Mushrooms are a perishable commodity and cannot withstand transportation over long distances without refrigeration. A measure of market preference must also be determined. Some large metropolitan centers may exhibit a demand for cream or brown mushrooms while others prefer only white mushrooms.

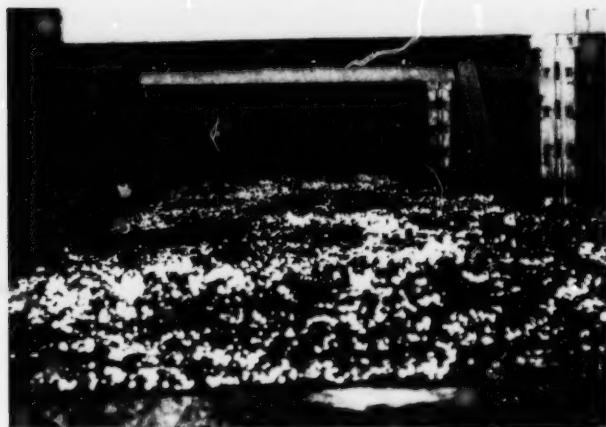


Figure 1. Center post bed system

In a discussion of economics, the question of type of farm is always debated. There are six basic styles of commercial mushroom farms. The most common type in North America is the bed system in which all stages of production from Phase II through to cropping are accomplished in one room (Figure 1). The ability to mechanize the handling of movable trays has prompted the popularization of the tray technique (Figure 2). Separate Phase II, spawn run and pinning rooms are used to supplement the cropping area (Figure 3). The separate rooms can be fitted so that optimum environmental conditions are available for each specific stage of development (Figure 4). The tray plant has a much higher capital cost than a bed plant but can produce more mushrooms per square metre. The Dutch system, which employs bulk Phase II and spawn running, is receiving a great deal of attention in North America (refer to Tunnels). While this method also has a high capital cost, it allows a basic bed plant to

approach the production levels achieved in the tray system (Figure 5). The majority of mushroom production in France occurs in abandoned limestone mines or caves. Lack of suitable sites in Canada has reduced the adaptability of this technique. In the U.S. a few cave operations can be found. A fifth system is the use of plastic bags to hold the compost rather than expensive beds or trays. Racks must be built to hold the bags since placement only on the floor reduces the potential production area. Plastic bags can be considered to be miniaturized tray operations. Specialized bag filling and handling equipment is required. Low capital costs are the major advantage. The final system is a compact plant in which the beds or trays are packed into a growing room without sufficient space for working with the crop. The beds or trays, placed on rollers, have to be taken out of the room to perform operations such as watering and harvesting, etc. A large production area is concentrated in one growing room. High initial and operating costs have reduced the popularity of this system.



Figure 2. Mechanized system for filling, spawning and casing trays



Figure 3. Trays are moved to rooms specially designed for the particular stage of the crop



Figure 4. Trays are arranged in a cropping room just prior to terminating the crop

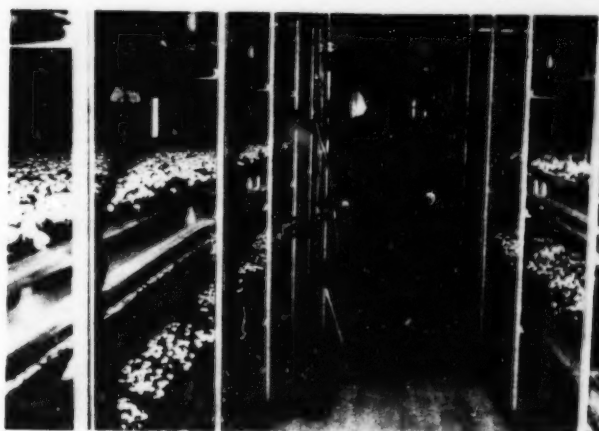


Figure 5. Interior of the smaller production rooms associated with the Dutch system. Note watering machine which allows for multiple bed application.

Supporters of the various techniques can present data to show the economic superiority of each. The number which is most critical is the production cost per kilogram of first-quality mushrooms. This calculation must include a value for depreciation, interest, taxes, etc. to be meaningful. A production survey conducted in 1977 by the Economics Branch of the Ontario Ministry of Agriculture and Food provides an excellent basis for the calculation of the cost of production. Another consideration is the availability of labor. If labor is a problem, the grower may have to move to a system which has a higher capital input in order to minimize labor costs, which are the highest single cost of mushroom production.

Preparation of Compost (Phase I)

In commercial mushroom production, nutrition is provided by a specially prepared material called compost. The composting process has two functions:

- (a) to obtain a substrate which is selective for the growth of mushrooms; and
- (b) to obtain a homogenous (physical and chemical) substrate.

Mushrooms are saprophytic organisms and rely on non-living organic material for their nitrogen and carbon nutrition. Mushrooms can absorb certain carbohydrates, nitrogen-rich lignin humus complexes and microbial proteins which become available upon the breakdown of several microbes. These microbes include the thermophilic (heat-loving) organisms such as the Actinomycetes, *Humicola*, *Torula* sp., *Chaetomium thermophile*, *Pseudomonas* sp. and thermo-tolerant mesophiles. These organisms are all involved in the conversion of inorganic nitrogen to nitrogen containing organic compounds, by using easily digested carbohydrates. It is important to note that all microbes involved are aerobes.

For years, horse manure has been the basic ingredient for the preparation of compost. This is not without reason since horse manure contains a high percentage of straw (carbon source), a source of microorganisms including some of those described above, ammonia (nitrogen source) and, in addition, has a physical structure which suitable for mushroom culture. Moisture is a very important ingredient in the composting process. By its very nature, straw is able to absorb large quantities of moisture and still allow sufficient pore space to prevent anaerobic conditions. The shorter the straw, the easier the moisture uptake will be. By trampling the straw, horses help to create a product which is suitable for composting.

The nitrogen content of horse manure depends to a large extent on the ratio of straw and droppings. The horse droppings in the bedding are the major additional source of nitrogen to the 0.3 to 0.5% nitrogen already present in the straw. Nitrogen levels of straw-bedded horse manure vary from 0.7 to 1.2%. The higher the N levels in the horse manure, the lower the cost of artificial supplements. Manure from the racetracks is usually lower in nitrogen than that from boarding stables, due mainly to the frequency of changing the bedding. Fresh horse manure is preferred for the preparation of compost. Anaerobic materials should not be used under any circumstances since the appropriate microbes will be absent. Depending on the initial nitrogen content of the horse manure high nitrogen-containing supplements such as chicken manure (2 to 6% N), dry brewers grain (4% N), urea (46%), S-90 (8.0 to 9.0% N), ammonium nitrate (34%), or cottonseed meal (7% N) may be added. Research has shown that the nitrogen level should be increased to 1.5 to 1.7% (on a dry weight basis). In Ontario, chicken manure, brewers grain and S-90 are the most common supplements. In addition, these organic supplements contain readily available carbohydrates which activate the development of the microbes. Agricultural gypsum (CaSO_4) is added to give the compost a good structure by reducing greasiness through flocculation of colloidal particles in the compost. Table 1 is one sample formula for the preparation of mushroom compost to fill about 360 m² of bed surface using horse manure.

Table 1. Example Formula of Mushroom Compost

	Wet weight (tonnes)	Dry weight (tonnes)	% N	Tonnes N
Horse manure	40.0	25.0	1.2	0.30
Chicken manure	3.75	3.0	4.0	0.12
Brewers grain (dry)	1.25	1.25	4.0	0.05
Gypsum	0.6	0.60	0	0
		29.85		0.47

Nitrogen content is $0.45 \times 100 = 1.57\% \text{ N}$
29.85

The nitrogen and moisture content of horse and chicken manure varies considerably depending on its source and age. Mushroom yields depend on the nitrogen content of the compost as well as the amount of dry matter per square metre at the time of filling. A nitrogen content of about 1.5 to 1.7% (dry weight) at the beginning of Phase II seems optimal for most growers. The rates of supplements often play an important role in the final decision on the ingredients for the compost. According to European studies, broiler chicken manure is preferred over manure obtained from laying hens due to different feeding ratios. Hardwood shavings, commonly used for bedding on chicken farms, do not seem to have any detrimental effect on the compost. Many different ratios of shavings and droppings are possible, consequently the nitrogen content varies greatly by source but is usually in the vicinity of 2 to 6%. When horse manure is in ample supply, European mixes consist generally of horse manure, chicken manure and gypsum.

The rate of gypsum (CaSO_4) to be added to the compost is based on the total amount of initial dry matter. A rate of 2 to 3% is minimal and higher rates are often beneficial. The finer the material is, the more effective it will be in preventing the compost from feeling greasy.

In many areas, horse manure is in limited supply or unavailable. In the first instance a synthetic compost can be prepared usually based on straw or hay and corncobs and added to the horse manure. Rye or wheat straw is recommended where a synthetic compost based on straw alone is being prepared. These types of straw contain a relatively high level of cellulose (30%) compared to oat and barley straw, the latter containing more easily digested carbohydrates. In practical terms, rye and wheat straw remain more sturdy during the composting process and therefore provide a more open structure in the compost. Chicken manure is added to the straw together with water, prior to mixing it with the horse manure to help start the composting process.

According to Dutch recommendations, about one-half of one tonne of chicken manure is added to one tonne of dry straw. Water is added to the point of runoff to initiate the composting process.

A flat pile of the mixture is made and let stand for 8 to 10 days. After this period the synthetic mixture is added to the fresh horse manure pile in a 30 to 70% ratio, again in a flat pile of less than 50 cm in depth. Broiler chicken manure is added at the rate of 100 kg/t of mixture. After four days the mixture is irrigated and compacted. This allows the mixture to absorb the moisture. This process takes about three days. At this point the compost piles are set up by machine (day 0). At day four, gypsum is added at 2 to 4% of the dry weight of the material and the pile is turned again and water is added according to the need. Successive turns are made

every two or three days thereafter, depending on the temperature within the pile.

Synthetic compost is based on hay, usually alfalfa or timothy, and corncobs. The nitrogen content of hay depends on source, cutting, time of harvest, etc. Good quality hay is from the early cut, leafy stems which are not too coarse, with few weeds and no molds present. Corncobs supply carbohydrates, lignin and cellulose compounds which are easily taken up by the composting organisms. Corncobs replace straw in the former examples. Breaking the corncobs so that the pith shows will improve accessibility by microorganisms.

An example for the preparation of synthetic compost to fill about 360 m² of bed surface based on hay is given in Table 2.

Table 2. Example Formula of Synthetic Compost

Ingredient	Wet weight (tonnes)	Dry weight (tonnes)	% N	Tonnes N
Hay	7.5	6.0	2	0.12
Corncobs	7.5	6.0	0.3	0.018
Chicken manure	2.0	1.6	4	0.064
Ammonium nitrate	0.15	0.15	34	0.051
Potash	0.15	0.15	0	0
Gypsum	0.3	0.3	0	0
		14.20		0.253

Nitrogen content is $0.253 \times 100 = 1.78 \text{ N}$
14.20

Again this is just an example, based on hay and corncobs on a 1:1 basis (dry weight). The ratio of hay and corncobs is usually 1.3:1.5. The nitrogen content of synthetic compost is slightly higher than that of horse manure-based compost (1.80 versus 1.60% N).

Stacking and Turning

A prewetting period of horse manure, hay, corncobs or straw is often preferred to start the composting process. Prewetting of horse manure or hay is achieved in a flat pile to which moisture is added to the point of runoff, and by driving a tractor back and forth over the pile, letting it sit for a few days to stimulate the composting activity. Considerable improvement of water uptake is achieved by crushing the straw, hay or corncobs. Some supplements can be added to this pile as well, to assist the composting process and to insure proper distribution. Excess moisture can be collected and recycled. This reduces unnecessary nutrient losses especially when water soluble organic sources are used.

After the prewetting period and the composting process have started, the remaining N supplements are added and stacks (piles) are made (Figure 6). The dimensions of an initial stack are about 2.0 to 2.2 m high and 1.8 to 2.0 m wide, with a variable length. Shorter materials require smaller piles to prevent compaction and consequent anaerobic conditions. Larger piles are used during the cold winter months.

Composting machines, commonly called turners, are uniquely designed for the composting process (Figure 7). The compost materials are picked up by a rotating drum which throws it onto a conveyor belt. Water may be added at this time. When the materials are at the end of the conveyor, fast-turning beaters throw the compost into a



Figure 6. Mechanical establishment of the pile from a rough mixture of raw materials



Figure 7. Large specialized machinery is required for the regular turning of the compost during Phase I.

container which controls the width and height of the required stack. Sides of the compost piles must be firm, allowing insulation for the inner part of the pile. The top should be relatively loose enabling the heat and accompanying gases to escape. Turns are made every two to four days, depending on the activity of the compost as well as its stage of completion. The higher the activity of the compost, the shorter is the time interval required between the turns to prevent anaerobic conditions. The temperature of the pile usually is an indication of the activity of the microorganisms. The temperature in the center of the pile should reach at least 70 to 75°C before turning. Composting will tend to make the strands of the straw and/or hay softer; undesirable anaerobic conditions due to compaction and high moisture content may develop. Thus, time intervals between the turns should be shortened during the latter stages of Phase I. A turning schedule starting at day 0 (stacking), and continuing on day 4, 7, 9 and 11, would be considered normal.

Due to the loss of water during the composting process, additional moisture may have to be supplied at each turn. The moisture losses during the summer months are generally higher. During the winter, it is good practice to add the moisture during the first or second turn. Compost tends to become wetter as it matures, especially during the winter when the rate of evaporation is low. An excessively wet compost may cause serious problems during Phase II. The optimal moisture content of the compost at the time of filling is between 70 and 74%, depending on the structure of

the product. The shorter the compost, the lower the optimal moisture content is in the compost.

The final product of Phase II should be a homogeneous dark mixture with a moisture content of 70 to 72% and a pH level between 7.5 to 9.0. The compost should be free from strong amide odors which are indicative of anaerobic fermentation.

Physical Requirements of Composting Areas

The composting process is dependent on the ambient temperature. Moreover, a properly composted material is essential to provide a good base for the remainder of the cropping cycle. Traditionally, Phase I is performed outside on concrete slabs or wharfs (Figure 8). Due to tighter scheduling demands and the need for greater control during this stage of the cycle, some growers have made provisions to protect the composting wharf from extreme weather conditions. Protection varies from windbreaks to completely enclosed areas sheltering the composting wharfs (Figure 9). Building materials for a composting shed must withstand high relative humidity and high levels of ammonia. Good ventilation should be provided, especially during the winter months, despite considerable heat loss. Provision for drainage should be made to collect excess water and nutrients for recycling.

The size of the composting wharf will depend on the volume of the compost needed to fill the mushroom houses. It must also be remembered that turners and tractors need ample area to maneuver. A composting area of 50 × 15 m for a weekly production of 40 t of compost can be used as a general guideline.

Composting wharfs are often close to the growing areas to facilitate filling of the houses. For sanitation reasons, it would be ideal if composting occurred some distance from the growing houses. The compost piles may be a source of disease or be re-contaminated from the growing rooms.

Because of the change in availability and/or price of composting materials, provisions for a dry storage area must be made. Horse manure, hay, straw, chicken manure, etc. can, if necessary, be stored for later use. However, precipitation in the form of rain or snow on horse or chicken manure may start an unwanted and uncontrolled composting process. This may make these materials unsuitable for later use.



Figure 8. Compost undergoing natural fermentation in piles on traditional composting wharf



Figure 9. A covered composting area with large windows, door and roof vents necessary for ventilation

Cook-Out (Phase II)

After the preparation of the compost (Phase I), the next phase can be started. The compost is filled into beds or trays. The filling procedure for a bed system has made great strides in recent years. Advancing from filling the houses manually by means of a pitchfork and wheelbarrow, growers began to use telescoping conveyor belts which could be operated within a house. This conveyor belt could be wheeled in, or out of, a house moving it over rails placed on top of the catwalk. At the end of the conveyor belt there was a reversible cross conveyor which would shoot the compost to either side of the center walk. The bottom beds were filled first, then the boards of the bed immediately above were put in place and then this layer would be filled. Although the filling procedure was mechanized, it did not solve the labor-intensive emptying procedure.

A more recent development has been loading the compost at one end of a bed onto a nylon net which is pulled over the bed boards by a pulley and cable system situated at the other end of the bed. The nets remain in the house until the end of the crop at which time the net is pulled out thus unloading

the compost at the end of the bed. In the tray system, trays (1.20 × 1.80 m) are usually filled with a special tray-filling machine and are mechanically emptied by some form of dump-shaker.

The purpose of the cook-out is twofold. The fermentation process is continued so that nutrients are formed which can be taken up by the mushrooms. Secondly, the cook-out is aimed at eliminating any parasitic organisms which may compete with the mushrooms. The cook out is considered to be one of the most important prerequisites of a good mushroom crop. An optimal cook-out can be obtained by proper manipulation of the environmental variables such as air and compost temperature, relative humidity, and carbon dioxide levels. On the basis of the environmental conditions, four states can be distinguished:

- (1) Prepasteurization period (1 to 3 days)
- (2) Pasteurization period (4 to 9 hours)
- (3) Conditioning period (5 to 12 days)
- (4) Cool-down period (1 to 2 days)

Maintaining a proper temperature is very important. Insulation of the pasteurization room must be consistent with the climatic conditions in the area. Perimeter heating, live steam, adequate ventilation and air circulation systems are required to achieve a proper Phase II. Measurements of the air and compost temperature can easily be accomplished with thermometers fitted with long leads into the room.

Pre-pasteurization Period

Filling a house with compost should be done as quickly as possible, avoiding excessive heat losses and thus reducing the activity in the compost. The amount of compost to be used depends largely on the air-handling capacity of the room. A useful guideline would be about one tonne fresh weight of compost per 10 m² of bed surface. The moisture content of the compost should be about 70 to 72%, depending on the structure of the compost. Even distribution of the compost in the beds will provide a more uniform Phase II process and facilitate the spawning and casing operations.

At filling, the compost temperature may vary greatly between different locations within the house. Temperature differences of 10 to 15°C may be expected. Circulation of

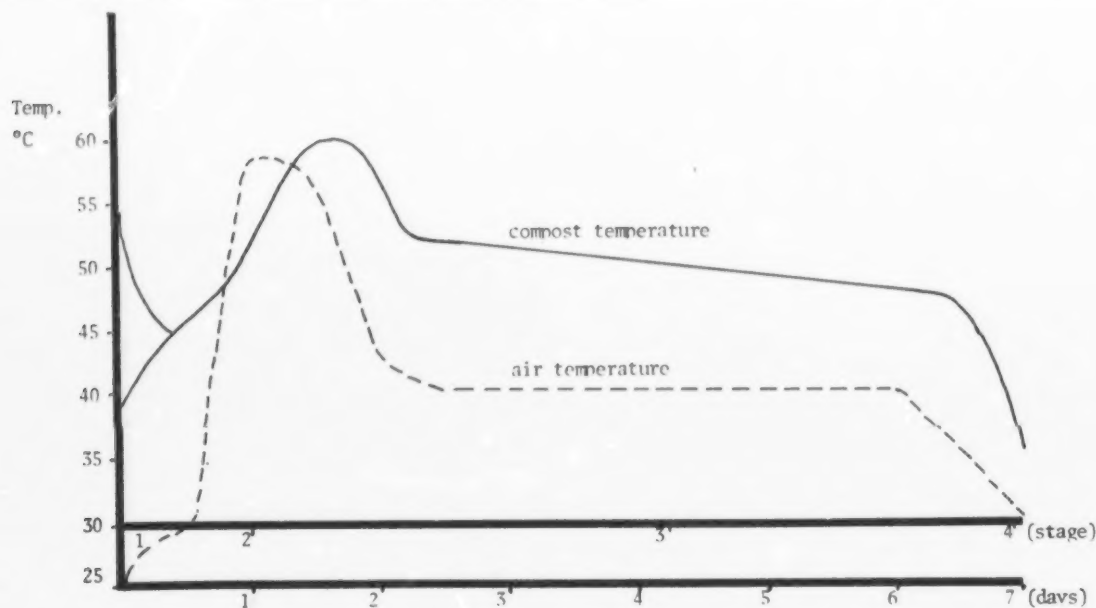


Figure 10. Schematic drawing of typical Phase II process

the air mass within the house will help to alleviate any large temperature differences in the compost.

Compost temperature should be maintained between 51 and 55°C with generous ventilation until the compost temperature drops 0.5-1°C or the first violent release of ammonia has subsided. This usually takes 2-4 days depending on the compost. The change in compost temperature or ammonia release is a signal that the pasteurization process can be started.

Pasteurization

This process is needed to eliminate any parasitic organisms such as fly larvae, mites, nematodes, fungal spores and other diseases. These organisms will be killed when the temperature in the compost is at 60°C for about 2 to 4 hours while maintaining a high relative humidity. To obtain these conditions, it is advisable to inject live steam into the room to increase air temperature. It is preferable that this process occurs quickly and thus sufficient steam should be available. When the air temperature has reached approximately 58°C, the steam inlet must be regulated to maintain the air temperature at this level. The compost temperature will show a delayed temperature increase. When it has reached about 56 or 57°C, the steam inlet can be closed off. The temperature of the compost will continue to rise. It should be prevented from rising above 60°C. The compost temperature at 60°C and an air temperature of about 50 to 66°C should be maintained for 2 to 4 hours. Some growers have aimed for a compost temperature of 65 to 70°C for a similar time period. This situation, called a high temperature cook-out, should be **avoided** since beneficial microbes such as thermophilic organisms and actinomycetes may be eliminated as well.

During pasteurization, checking temperatures every half hour is necessary so that adjustments can be made for any irregular temperature fluctuations. The temperature readings should be noted on a chart and recorded for a duration of the crop cycle.

In some situations, the temperature for the compost immediately after filling remains at a high level (50 to 60°C) even when the air temperature is at 30 to 35°C. Raising the air temperature for the pasteurization process to 58°C will create a tendency for the compost temperature to exceed the desired upper limit of 60°C. Pasteurization should then be delayed until the natural activity of the compost has decreased. This may take another one or two days depending on the activity of the compost.

Conditioning of the Compost

After eliminating the parasitic organisms and thus providing more "growing" space for the beneficial organisms, the composting process can be completed. This is done by proper manipulation of the temperature, relative humidity and CO₂ content so that the beneficial organisms can develop under optimal conditions. The desired temperature for the thermophilic organisms is between 50 and 55°C.

After pasteurization, the air temperature can be dropped to about 40 to 45°C so that the compost temperature will decrease to about 55°C. Air temperature should then be adjusted in such a way that the compost temperature decreases slowly from 55 to 50°C at a rate of about 1 to 2°C per day. During this conditioning period, the room must be supplied with sufficient oxygen to keep the compost aerobic. An estimate of 20 to 50 m³ of fresh air per tonne of compost per hour should be introduced, especially during the early stages of the conditioning period. The supply of fresh air may create an increased activity in the compost and care should be taken to prevent reheating of the compost. As the

conditioning period continues the amount of fresh air required is reduced. Not only does the supply of fresh air provide the necessary oxygen, it also removes some of the moisture from the compost. The moisture content generally decreases 5 to 7% from the original 70 to 72%. Excessive moisture losses can be avoided by maintaining a high relative humidity.

During the conditioning process the compost will lose its stiffness and grayish-white molds will become visible on the straws. The ammonia smell will diminish slowly. It is often the absence of this ammonia odor which tells the grower whether the composting process has finished. The conditioning period will usually take at least five or six days.

Cool-Down Period

After the ammonia smell has disappeared, the compost may be cooled down to about 25°C. In Europe it is recommended that cooling be accomplished within two to four hours. American research indicates that a slower time of one or two days is preferred. However, flies seem to be attracted to pasteurized compost. If flies are in great numbers, especially sciarids, the cool-down period should be short.

A recent development in the mushroom industry has been bulk pasteurization (see Tunnels). Air is forced through the bulk pile from the bottom up, then removed from the top of the compost pile and mixed with the desired quantity of fresh air and recirculated through the compost. The main advantage of bulk composting is that air and compost are nearly the same temperature. No significant temperature differences should occur within the pile, resulting in a very uniform composting process. Less energy is needed for cook-out due to the air recirculation technique.

In summary it should be emphasized that the cook-out process is complex. An example of an idealized situation has been given in Figure 10. **At all times** fresh air must be allowed into the house. The amount depends on the activity of the compost, outside conditions, and the stage of the cook-out. Circulation fans to obtain proper mixing of the air will help prevent temperature stratification within a house.

The total time for a cook-out varies from 7 to 14 days, depending primarily on the air-handling system, Phase I, and the amount of compost filled. The pH of the compost will finish at around 7.5 and the compost should have a moisture content of 65 to 67% and an N content of about 2.1 to 2.3%. In the meantime, the dry weight of the compost will also have decreased substantially (15 to 25%) from the time of filling.

Due to the importance of the cook-out, it is recommended that at least three thermometers, checked for accuracy on a regular basis, be provided. Thermometers with long capillaries

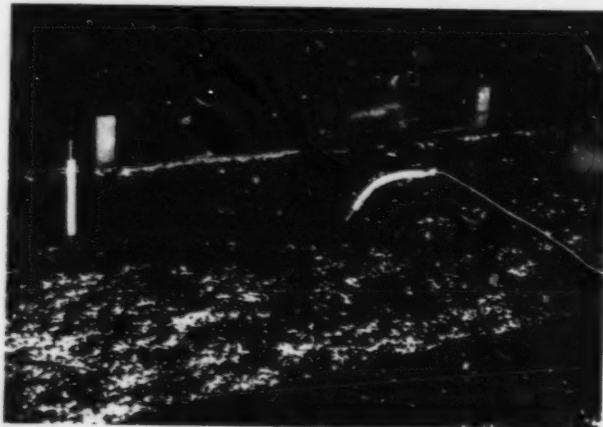


Figure 11. Thermometers with leads to permit remote readout

will make checking a more pleasant job (Figure 11). Recording the temperature data may provide some insight into why certain houses perform better than others.

Spawning

After the cook-out, the compost is "seeded", or more commonly called spawning. The "seed" is called spawn.

Spawn Preparation

Spawn is usually selected, propagated and prepared by special laboratories. Very few growers produce their own spawn due to its specific needs and exacting requirements. Under sterile conditions a piece of mushroom tissue is placed on a nutritive substance such as a potato-dextrose agar. Vegetative growth (mycelia) will develop from this tissue under proper conditions. For propagation purposes, this mycelia can be transferred from one nutrient culture to another by sterile transfer. To obtain spawn, mycelia are transferred to sterilized grain kernels contained in plastic bags or glass bottles. At a temperature of about 25°C and a high relative humidity, the mycelia will grow on the grain kernels. When the kernels are completely covered with mycelia (two to three weeks), the spawn is ready for use as "seed" (Figure 12).



Figure 12. Cereal grains coated with mycelia growth ready for spawning

Spawn

There are two genetically distinct *Agaricus* species on the market. The most common is *Agaricus brunnescens* (*bisporus*). The other is *Agaricus bitorquis*. The latter species grows best at a higher temperature "hot spawn" and needs slightly different cultural practices. Currently, less than 1% of Canadian production is *A. bitorquis*. The following discussion relates to *Agaricus brunnescens*, unless otherwise specified.

Within a species there are several distinct strains or lines. These strains are usually labelled by a number. There are white, off-white (cream) and brown strains, indicating the color of the mushroom cap at maturity. In Ontario at least 75% of the production is from the white strains while the remainder is from off-white and brown strains. Each strain has its specific characteristics, cap shape, color, size and growing habits. These morphological differences can usually be supplied by the spawn producer.

A recent development in mushroom strains is the creation of hybrid varieties. These new strains generally produce

larger yields and can remain on the beds longer than the non-hybrid counterpart. However, these new genetic lines are more difficult to cultivate. Regardless of the difficulties involved, at least 75% of the mushrooms cultivated in North America are hybrid varieties.

Spawn is usually sold on a volumetric rather than on a weight basis. As a general guideline, one litre of spawn weighs about 0.6 kg. Presently there is one commercial spawn producer in Ontario, located in Richmond Hill. Several American-based spawn producers sell through local agents. At the farm, spawn should be placed in refrigerated storage, at about 2°C, until ready for use.

Spawning Procedure

The optimal moisture content of the compost at spawning is 65 to 67%. When the compost is too dry, water can be misted on the surface of the beds before spawning. The temperature of the compost should be around 25°C.

Although there are several different spawning procedures, only the most common technique will be described. Spawning rates may vary depending on the amount of compost per square metre, the air-handling system and the time allowed for the mycelium to colonize the compost. A general guideline for the application rate would be 0.8 L/m² or 0.5 kg/m² or 0.5% on a wet weight basis.

About 80 to 90% of the spawn is spread by hand over the beds as uniformly as possible. The spawn is then worked into the compost by a spawning machine, a rotavilling type of device which allows a more homogeneous mixture of the compost and spawn (Figure 13) or a pitchfork. There are spawning machines which dig about 5 to 10 cm into the compost, while others go the entire depth (through spawning). The surface of the compost should be smoothed out prior to seeding the remaining 10 to 20% of the spawn. This allows a rapid penetration of the mycelium into the surface combatting any antagonistic organisms which may come from the air or are carried along with clothes or hands. Proper sanitary measures must be employed to avoid any undesired infection. The shape of the bed surface may be flat or convex. When a mechanical "roughening" procedure is employed, the flat bed surface would be preferred. The compost is then packed down by means of a roller or a piece of board and covered with a thin layer of plastic or paper.



Figure 13. Two spawning machines used for incorporating spawn into the compost. Unit at the top shows tines which penetrate the compost.

Nutritional supplementations may also be added at the time of spawning. These products increase the yield potential of the compost as much as 25%. Extra metabolic heat is, however, generated during spawn-run and precautions are necessary to avoid excess heat buildup which is harmful to the mycelia.

Environmental Requirements

The optimum temperature for the development of the mycelium is about 24 to 26°C. Temperature exceeding 30°C should be avoided. The relative humidity should be 90 to 95%. A high level of CO₂ (2 to 3%) is beneficial for mycelial development. Air circulation fans should be used to avoid temperature differences within the house. The amount of ventilation needed depends on the natural airtightness of the room and the bed temperature. To obtain the conditions required for optimal growth, many growers use a polyethylene or paper covering over the spawned compost. A high relative humidity and a high CO₂ content are created under the cover (paper should be wetted regularly), which also acts as a physical barrier to flies by preventing them from laying their eggs in the beds. This stage of the mushroom production cycle should be watched carefully to avoid infestation from flies, because the odor produced by the growing mycelia especially attracts phorids.

Spawn should show signs of growth within two to three days after being added to the compost. Fine hyphae should grow out from the kernel (Figure 14). During this growth, heat will be produced which must be dissipated from the compost. Bringing cool air into the house may become a necessity, especially when the mycelia becomes very active (7 to 10 days after spawning). The air temperature is usually 2 to 5°C lower than the compost temperature at this stage.

The mycelia will completely cover the compost in about 12 to 16 days. This time period depends on temperature as well as the ratio of spawn to compost. The color of the compost will have changed from black to a brown/yellow color.

When the mycelia has colonized the compost (80 to 90% of the surface shows a white coating), the casing layer can be applied.

Casing

The only economical method of forcing mushroom mycelia to convert from the vegetative phase to a reproductive state is to apply a 3 to 5 cm layer of a suitable material on the surface of the spawned compost. This layer is called the casing layer. There is a wide range of suitable materials which may provide an environment necessary for the induction of fruit body formation.

The precise mechanism which initiates the change from the vegetative to the reproductive phase is unknown but several theories have been presented. The most popular concept is that microorganisms in the casing material produce metabolic products which include a change in the lipid metabolism of the growing mycelia, resulting in the formation of pinhead initials.

Materials

Growers in North America have traditionally used a loam topsoil as a casing layer. The soil must be pasteurized before use in order to eliminate weeds, competitive fungi, bacteria and nematodes. Increasing costs for stripping the soil from the fields, lack of convenient sources and variability of supply have caused growers to seek alternatives.



Figure 14. Spawn beginning to colonize compost

Peat Moss

In the last decade Canadian producers have shifted to peat moss or combinations of peat and soil. Sphagnum peat is relatively inexpensive and readily available in this country. One compressed bale (0.17 m³) will cover 8 to 10 m² of production surface, depending on casing depth. Since sphagnum peat has a pH of 3.5 to 4.5, a neutralizing agent must be added to bring the pH level up to 7.5. Calcitic limestone mixed in a ratio of 1:1 on a dry weight basis with the peat will provide the required effect. The use of dolomitic limestone should be avoided since yield reductions have been reported. Hydrated lime [Ca(OH)₂] has been used with some success. Due to a higher neutralizing capability and its greater solubility, only small amounts (25 g/kg) are required. Excessive amounts of hydrated lime may produce a pH of 9 or even higher. Since mycelia produces acidic compounds during growth, the pH of the casing layer will drop if only hydrated lime is used. Some growers choose to use a combination of limestone (1:2) and hydrated lime 20 g/kg) to obtain both the quick reaction of the hydrated lime and the buffering effects of the limestone. If hydrated lime is used, care must be taken to obtain mixing throughout the casing and not to apply excessive amounts of the material.

The major advantages of peat include a high moisture-holding capacity, an adequate gas exchange from the compost, uniformity and general freedom from insect and disease pests. Because of the latter characteristic some growers do not pasteurize peat prior to use as casing, a practice not generally recommended unless strict sanitation measures are maintained on the farm. Oversteaming of peat must be avoided since substances which are toxic to mushroom growth may be released. Breakdown of the peat structure is also a detrimental side effect of over-pasteurization. The major disadvantages of peat are high cost and the difficulty of getting water into the peat on the first mixing. If not properly handled, peat will also give a higher incidence of dirty mushrooms because of pinning under the surface. When mushrooms are harvested, peat particles tend to adhere to the stump and mycelium. Some growers counteract this by putting some topsoil with the peat to give the casing more "weight".

Spent Compost

The use of weathered spent compost as a casing material has been used with success. There have been no precise guidelines developed as to when the spent compost can be reused. The most critical factor appears to be the level of total salts in the compost. When compost is emptied from a house the salt level may be in excess of 5.0 milliSiemen per centimetre (1:2; soil to water ratio). This must be reduced to below 1.0 mS/cm before the spent compost can be used. The most practical method of reducing the salt level is by the natural leaching effect of rainfall after the material has been spread on a field. This weathering process also allows for a decomposition of the hay or straw in the compost to the point when the spent compost is ready for use and looks almost like soil.

After steaming off a house the compost should be spread on a field to a depth of 30 to 35 cm but not more than 50 cm. Approximately 20,000 m² of bed area can be spread on one hectare of land. After spreading the material in the field it should be cultivated regularly to keep down weed growth during the first year. Cultivation also assists in a more thorough weathering process. After two full years of exposure the material is generally suitable for use as a casing. Some growers prefer to grow a green manure crop on the field during the second or third year. Herbicides should not be

applied to this green manure crop.

Spent compost can be used alone or in combination with soil or peat moss as a casing layer. It must be pasteurized prior to placing on the bed to insure no carry-over of pathogenic organisms from the previous crop.

Topsoil

Loam topsoil was the traditional casing material. An area of one hectare will provide sufficient material to case 75,000 m². Soil must be pasteurized before use in order to kill weed seeds, insects and diseases. The pH should be adjusted upwards from 7.0 to 7.5 if the soil is acid. Different soil types require alternate management techniques. Clay loams have a tendency to seal while sandy loam has an insufficient water-holding capacity and cannot hold adequate moisture for good crop growth.

Waste Products

Research is continuing at several institutions to determine alternate materials for the casing layer. The objective of most programs is to find a waste product which can be converted into a suitable casing compound. Such diverse sources include paper mill waste, wormcasting and decomposed wood chips.

Pasteurization

Eradication of pests in the casing soil is required before the material is added to the compost. Even when peat moss is used as the casing, some growers will pasteurize the material to insure that it is free from insects, diseases and weed seeds. Both heat treatment and chemical fumigation have been used successfully to control pests.

Heat

Three basic methods of heat pasteurization can be used. Dry heat, such as that generated by an electrical soil sterilizer, can provide an excellent kill of pest organisms. It is difficult to achieve uniform heat flow in a soil mass using this technique. The possibility also exists of overheating or charring the soil. Dry heat is not generally used by commercial mushroom growers because of the large volumes required.



Figure 15. Bulk, aerated steam system in which air is mixed with the steam by the unit on the left and then forced into the wagon.

The use of moist heat or steam is the most popular method in Ontario. Most growers inject free-flowing steam into a network of perforated pipes covered with a given volume of casing soil. The object of the pipe network is to provide several points of steam injection to insure uniform treatment and eliminate the risk of charring the soil. The casing should be heated to 70 to 75°C and maintained at this temperature for 30 minutes with the thermometer placed in the coolest area of the soil mass.

Steam is a nonselective sterilant. It kills not only the pathogens but also the desirable microorganisms. If a pathogen is accidentally reintroduced to the pasteurized casing it will grow rapidly throughout the casing because of a lack of competitive organisms. The use of aerated steam has become more popular since it reduces the recontamination risk (Figure 15). Aerated steam is produced when air is injected into a free-flowing steam line; this causes the steam vapor to disperse which results in a reduced temperature in the mixture. By regulating the volume of air, the steam-air mixture can be controlled at the desired temperature. The pasteurization process takes less time because of a more efficient heat transfer from the steam-air mixture to the casing material. Most mushroom pathogens are killed when the casing is treated at 60°C for five to six hours, but this does not eradicate all the beneficial microorganisms. This population of beneficial organisms can then actively reduce the possibility of recontamination. Other advantages of the use of aerated steam include reduced costs because a smaller boiler is required. The lower treatment temperature reduces the possibility of post-steaming toxicity induced by excessive pasteurization.



Figure 16. A stationary cement mixer used to produce a good blend of peat moss and neutralizing agent

A general guideline to assist in determining the size of boiler for pasteurization is that 2.8 mega Joules per cubic metre per Celcius degree must be added to heat the soil. If 5 m³ were to be heated from 20 to 85°C in one hour a total of $2.8 \times 5 \times 65$ or 910 MJ/h would be required.

General Recommendations

The depth of casing soil is dependent on the material chosen. Two to three centimetres of loam soil is usually adequate while 3 to 5 cm of peat moss should be used. Some growers use as much as 8 cm of peat moss. When peat is used, it must be thoroughly wetted prior to adding to the compost surface, since it is difficult to get water into dry peat. Many growers use some type of converted cement mixer to provide uniform distribution of water and neutralizing agent in the peat moss (Figure 16).

Casing is generally applied to the mushroom beds after the compost is fully colonized. Depending on the rate of spawn, temperature and CO₂ levels, this is usually two weeks after spawning.

Many growers, 3 to 5 days after casing, will disturb the surface by redistributing or leveling the casing material. Growers take care not to disturb the mycelia growing into the casing. This procedure will help to produce uniform pin formation, and mushroom size and as well as reduce clustering or clumping of mushrooms.

For growers using the 'tunnel system', the casing layer is firmed on the surface immediately after it is applied. This supports a buildup of CO₂ in the compost and the casing, thereby stimulating mycelial growth. Seven to nine days later, the casing is completely raked or ruffled. A machine with rotating tines is used to thoroughly mix the **entire** casing layer. This process breaks up the mycelial strands and evenly distributes these throughout the casing layer. This technique will help to reduce clustering and provide more uniform flushes.

Cropping Cycle

The segment of the cycle in which fruit body formation occurs and harvesting is conducted can be broken into three distinct phases. This section will deal with prepinning and pinning, cropping and emptying the house.

Prepinning and Pinning

The beds can be watered as soon as the casing layer has been applied. The amount of water depends primarily on the type and texture of casing material. Mineral casing layers (clay or loam-type) will not hold as much water as the organic types (peat moss or combinations of peat moss and soil). Moreover, organic casing layers are applied more thickly than the inorganic types. An estimate of the first two or three applications is between 1.0 to 2.0 litres per square metre per watering. Watering should not be allowed to penetrate to the compost/casing interface since this would result in the formation of a slime layer.

Compost depth and casing layer thickness should be uniform across the beds. This will allow uniform moisture distribution throughout the casing layer. Consequently more even growth of the mycelia into the casing can be expected. When there is sufficient moisture in the casing layer at the time of casing, the first watering can be delayed for one day, to allow the start of mycelial growth into the casing. Heavy waterings can then be applied the second and third day. After these waterings the moisture content should be between 70 and 75%, depending on the structure of the casing. Any waterings after this should be applied at a lower

rate, and should only compensate for the moisture evaporated from the beds (0.25 to 0.5 L/m² watering). Water meters will help to control the amount of moisture being applied. Record-keeping is essential so that the grower can relate experiences with substantiated information.

The temperature in the compost should be kept at the same level as during spawn running (25 to 27°C) for the first week after casing. Temperatures above 30°C may retard the mycelial development and will cause uneven growth. Very little fresh air is needed during this time. High CO₂ levels with high relative humidity are preferred during this vegetative stage. The relative humidity at this stage of the crop should be maintained at 90 to 95%. Floors and walls should be kept wet especially when large amounts of fresh air are used for cooling. Carbon dioxide levels may become as high as 2 to 3%, causing a negative effect on the mycelial development. Air circulation is needed at this time to maintain an even temperature distribution in the house. When a combination of high temperature and reduced air movement occurs, the mycelia may grow on top of the beds and form a dense network of hyphae, called "overlay". This phenomenon should be prevented as it will hinder the water infiltration into the casing as well as pinning. Ventilation is only needed when the temperature of the beds becomes too high. Excessive ventilation should be avoided to prevent pinning under the surface.

When mycelia has reached the surface, the pinning stage can be initiated. This is induced through cooling down the beds and by allowing fresh air to enter the house. The temperature in the beds should drop from 25°C to 20°C or below, while the CO₂ level should drop to 0.1% or lower. This will allow the hyphae to bundle and form pins which are the generative stage of mushrooms. The relative humidity in the air should be maintained at a high level to prevent drying out at the end of the hyphae and thus reducing the number of pins. A minimum relative humidity of 85 to 90% is advisable. The air temperature should be maintained between 16 and 20°C depending on the activity in the compost, and strain requirements for optimum size and yield. It takes about four to seven days after the cooling-down period before pins show on the surface. During this time no water is added to the beds. When the pins become the size of a small pea, watering is started again.

It is generally accepted that mushrooms absorb the majority of the moisture for development from the compost and not from the casing. The moisture in the casing prevents the mycelia from drying out and is especially needed for cooling of the beds. Heat is required to evaporate water; this heat is extracted from the beds. Ventilation induces evaporation from the beds with resultant cooling of compost. In addition, the ventilation increases transpiration from the mushrooms. This in turn causes the nutrients and moisture to flow into the mushrooms. The amount of fresh air also depends on the amount of mushrooms to be grown on the beds. At about 16°C in the beds, the CO₂ production is estimated at 60 mg/kg of compost per hour during the first three flushes. This will be two to three times higher at 26°C. After the pins are formed, the CO₂ levels at the top of the casing layer should be around 0.08 to 0.10%. For mushroom houses with roof vents, CO₂ levels are very difficult to regulate automatically or precisely. Growers with air-handling systems can regulate the amount of fresh air entering the room much more efficiently. Besides ventilation, circulation of the air is required. Circulation prevents CO₂ levels from building up between the mushrooms thus maintaining good quality. Mushrooms grown at high CO₂ levels are usually elongated and soft.

The temperature to be maintained in the air and/or the

compost largely depends on the ventilation capacity in each particular house. Mushrooms grow firmer under cooler growing conditions. However, the rate of development of the crop also determines the length of time a crop will be in the house. When growing at a higher temperature, more ventilation is required. Most growers try to maintain an air temperature of 17 to 19°C.

Cropping

Mushrooms come in flushes. The first two flushes produce the majority of the total yield, with the later flushes tapering off to relatively low levels of production. The interval between flushes is 7 to 10 days depending on the temperature. Cleaning the beds of late-maturing mushrooms will often shorten the time between flushes, as latecomers will delay the development of the next flush. The reason for this is not very clear. A possible explanation is that the mycelial threads need some time to absorb sufficient nutrients and moisture for the next flush. Trashing or cleaning the beds after a flush promotes development of the next flush and is not the lost effort many growers believe it to be. Some growers will pick six to seven flushes (40 to 50 days) and will then end the crop. Other growers try to produce just three to four flushes per cycle, to prevent the development of disease and insect problems. This also allows more crops to be produced per year.



Figure 17. Watering the mushroom crop by hand with a fine rose head requires experience and careful attention.

Watering the crops requires experience. The amount of water and timing of its application are critical. The total amount of water to be applied per flush depends on the expected yields; about one litre of water is required per kilogram of mushrooms (Figure 17). Frequent waterings can be applied after the pins have become the size of a small pea, and up to one or two days before the main pick. Watering mature mushrooms increases the possibility of discoloration of the cap. The addition of chlorine at a rate of 125 to 175 parts per million active ingredient may help to prevent blotching of the mushrooms. Increased ventilation immediately after watering will dry the surface of the mushrooms and reduce the increased CO₂ level which usually accompanies the watering.

Mushrooms are harvested when the cap is at its maximum size and before the veil under the cap stretches and opens. Picking is generally done by hand (Figure 18). The mushroom comes loose from the surface when it is given a slight twist.



Figure 18. Harvesting and grading mushrooms

The remainder of the mycelia is cut off with a sharp knife. Many surrounding pins may be damaged when this is done improperly. The mushrooms are then inspected and graded by size. The bigger ones (more than 30 mm in diameter) belong to Grade 1 while the smaller ones are called buttons. Open mushrooms are considered second-grade. Diseased, malformed and fly-damaged products are discarded. The picking rate depends mainly on the amount of crop on the beds, and varies from 15 to 30 kg/h. Diseased mushrooms should be removed in a separate operation and placed in a plastic bag. The diseased area on the bed is then treated with a pesticide.

While mushroom yields vary, the average yield for Ontario in 1984 was about 18 kg/m² per crop. With improving technology such as air-handling systems, fillings with more compost, supplementation, and improved strains this could be increased to 35 kg/m².

Emptying the House

When a house becomes unproductive, the crop is usually terminated. The house is then steamed off to eliminate any diseases or biological activity which could interfere with a neighboring house. This steaming-off procedure is accomplished by maintaining a compost temperature of 60°C for at least four to nine hours. The spent compost should be transported to a field far enough away to reduce the chances of contaminating the mushroom production at the farm.

Post Harvest Handling and Processing

Once mushrooms are harvested, they should be cooled quickly. After the mushrooms have been taken from the beds, they continue the respiration process. This process generates approximately 1450 kilocalories of heat from 100 kg of mushrooms per day at 16 to 18°C. Refrigeration will reduce the rate of respiration and weight losses will be kept to a minimum. The respiration rate at 10°C is 3.5 times greater than at 0°C. In addition to the heat of respiration, the produce contains "sensible heat" or "field heat". This heat must be removed quickly so that the mushrooms can achieve the lower respiration rate. Approximately 1600 Kcal/100 kg of mushrooms must be removed to bring the actual temperature of the produce from 20 to 3°C. Vacuum cooling is the quickest and most effective method of reducing the temperature of harvested mushrooms. This technique involves the use of a tightly sealed refrigerated container. The produce is placed in the cooler and the air pressure lowered while cooling the chamber. The temperature of the produce can be reduced to 2 or 3°C in 20 minutes using this technique. Less water loss and a better shelf-life are other benefits of vacuum cooling. Unfortunately the cost of a vacuum cooling installation is quite high and not feasible for most growers. As a substitute, a cooler with a

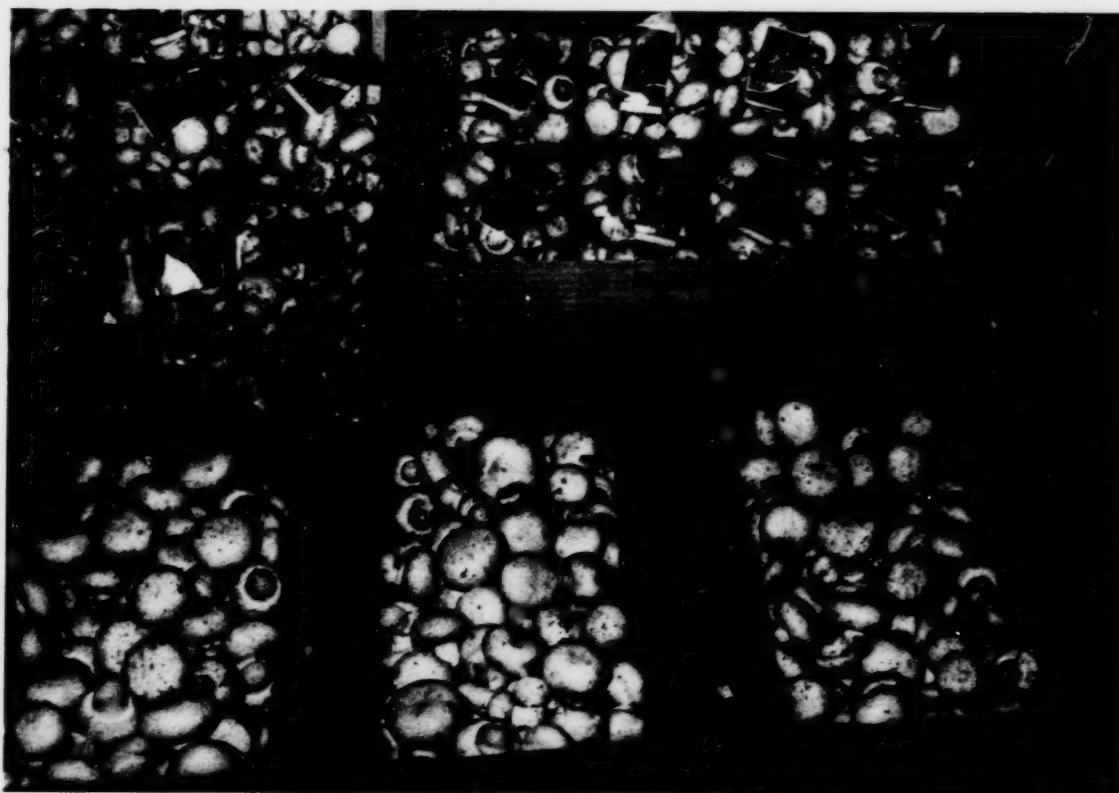


Figure 19. Plastic overwrapped trays and bulk containers of mushrooms for the fresh market

capacity of 1800 Kcal of refrigeration per hour per 100 kg of mushrooms would provide effective temperature reduction.

Once the mushrooms are cooled they should be transported in climate-controlled trucks to the marketplace where they should be displayed on refrigerated shelves. Failure to do so will seriously reduce quality. A large percentage of mushrooms are marketed in polyethylene film-overwrapped containers of 225, 340 or 450 g (Figure 19). The original plastic overwraps do not allow for "breathing" of the mushrooms and condensation quickly forms on the produce. Also, tight overwrapping can result in near oxygen depletion in the container which may enhance the growth of undesirable bacteria. Although there have been no reports of actual bacterial contamination resulting in the production of toxins on the mushrooms, it is recommended that each film overwrapped container be fitted with at least two 0.5 cm holes.

Very few mushrooms are washed after harvest since efficient drying is difficult and the remaining surface moisture would promote the development of bacterial organisms and thus spoilage.

A declining proportion of Canadian mushroom production is processed each year. In 1984, the percentage of mushrooms processed was about 30%. The principal form of processing is blanching followed by canning and sterilization. Equipment for processing is specialized. Few growers can seriously contemplate setting up a canning facility as part of their farm operation. A small volume of mushrooms are dried or frozen. In order to effectively process mushrooms, as with other vegetables, contaminant microorganisms must be inactivated. In addition, spontaneous chemical conversions an enzymatic activity within the product must be slowed or stopped.

Pest Control

Mushroom production represents one of the best examples of biological control in agriculture. By proper manipulation of the growing media and the environment, the majority of insects and disease problems can be controlled or eliminated. A proper Phase II can provide a compost which is selective for the growth of the mushroom fungus and restricts the development of many other fungi, bacteria and weed molds. Once the mushroom mycelia begins to grow into the compost it produces metabolic products which directly retard the growth of competing fungi and bacteria. Many serious pest problems can be traced to a poor or incomplete Phase II and the subsequent establishment of the pest since the mushroom mycelia was not sufficiently competitive.

Chemical control agents in conjunction with strict sanitation are excellent methods for supplementing biological control. Rates and timing for pesticide applications are given in Ontario Ministry of Agriculture and Food Publication 367, *Ontario Mushroom Pesticide Recommendations*. Too often growers rely on chemicals only to correct a pest problem. This can result in heavy applications of pesticides which in turn may weaken the mushroom growth. This cycle eventually leads to a greater problem with the best and ultimately reduced yields.

This section contains a brief outline of the major insect and disease problems with suggestions for control.

Insects

Sciarids

Sciarid flies (Sciaridae: *Lycoriella mali*) are currently considered the most important insect pest of commercial mushroom production in Canada. The adult fly is about 4

mm in length with long, thread-like antennae and large compound eyes which meet above the base of the antennae (Figure 20). The wing venation is distinctive in that the anterior veins are more prominent than the posterior ones, and there is a pronounced fork at the apex of the median vein. A female may lay up to 170 oval, white eggs (0.25×0.15 mm) either in the compost or casing or on the mushroom. The eggs can be laid singly or in groups of 10 or more. They hatch in four days at 24°C. The larvae go through four instars ("worm" stages), eventually reaching a length of 6-7 mm. The larva has a shiny black head. The larvae feed on Phase II compost, spawn grains, mycelia, developing pins, stems and caps (Figure 21). The burrowing in the stem is the most obvious damage symptom but the feeding on the mycelia can cause the greatest loss in yield.

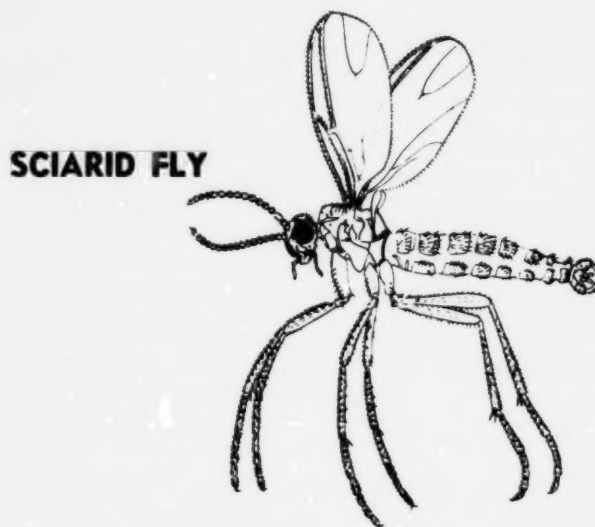


Figure 20. Sciarid fly, male

The sciarid becomes more active in warmer temperatures. The life cycle can be completed in 21 days at 24°C. Lower temperatures prolong the generation time to 38 days at 16°C. Below 7°C the larvae become inactive. Since the flies naturally infect wild mushrooms, this may present a source of infestation especially during the summer months. Mushroom flies are attracted to the odor of Phase II compost. It is critical that the fly populations be controlled from the time of cooling down after Phase II and prior to casing. The temperatures during these periods are optimum for development of the pest and an infestation at this time may result in extensive damage to the crop.

A preventive program is the most effective means of control. Physically inhibiting the insect from entering the production facility is critical. Sealing cracks in and around doors, walls, windows, air-conditioners is essential to good pest management. Sanitation between crops will provide an effective means of limiting the resident population but preventive insecticide applications may be required to control the flies when resident population is high. See OMAF Publication 367, *Ontario Mushroom Pesticide Recommendations* for specific chemicals and timing of application. Many growers cover their beds with thin plastic to prevent egg laying during spawn-run. The plastic also acts to hold moisture in the compost. It should be removed one day prior to casing to allow the compost surface to dry sufficiently to prevent the formation of a wet layer between the compost and casing.

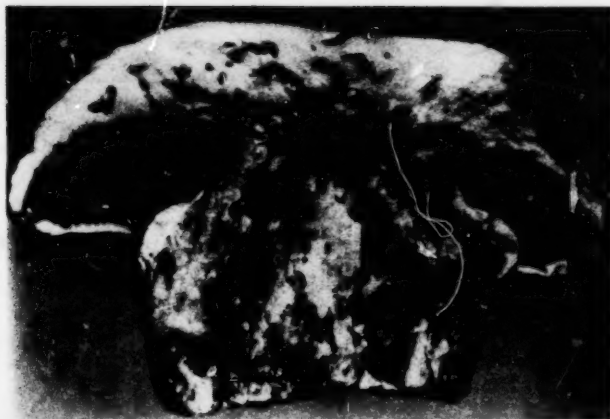


Figure 21. Damage caused by insect larvae in the mushroom cap (Vedder)

After casing, regular applications of dusts or fogging will be required to keep the fly population under control. Dichlorvos is not generally recommended during cropping since the carrier in the pesticide formulation may result in the production of distorted mushrooms often referred to as rosecomb.

Growers have installed black light traps in the growing house. These traps are useful for the purpose of monitoring peaks of fly activity in the house but do not act as a substantial control agent. Flies may be killed by the trap but this number represents only a minor proportion of the flies actually in the house. These monitors are necessary for determining effectiveness of a preventive program, timing of pesticide applications and evaluating pest management decisions.

Steaming off at the end of the crop is an excellent method of reducing the possibility of carry-over of eggs or larvae into the next crop. If the house is not steamed off, the spent compost will provide a good source of inoculum not only for flies but for many diseases. Although steaming the compost may make emptying the house more difficult, it is false economy to circumvent this sanitation procedure.

Phorids

Phorid flies are pests of commercial mushroom production in Europe and the United States. Their presents in Ontario mushroom production facilities is sparse. The predominant species in Eastern United States is *Megaselia halterata*.



PHORID FLY

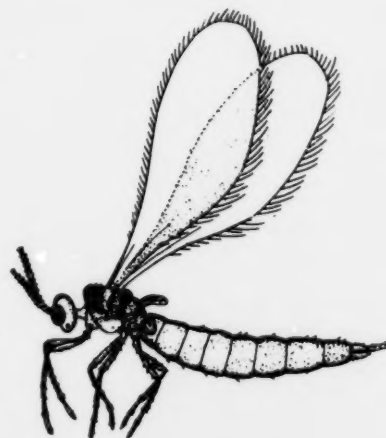
Figure 22. Phorid fly

Phorid flies can be distinguished from the sciarid fly by their body shape and quick jerky motion (Figure 22). The immatures are far less damaging than the sciarid. Phorid immatures feed **only** at the hyphal tips of the mycelia. This species does not tunnel into the stem or cap (other phorid species, however, may do such damage). Each female will lay up to 50 eggs usually in proximity to the growing tip of the mushroom mycelia. At 24°C, the spawn running temperature, the eggs will hatch in two days. The entire life cycle takes about 20 days at 24°C, 40 days at 18°C and 150 days at 7°C. The larvae, which are considerably smaller than the sciarid larvae, are white, almost transparent, and lack the black head of the sciarid fly. The adult is approximately 2 mm in length with absence of distinctive wing venation and a humped back body shape. Phorid adults are highly attracted to the odor of growing mushroom mycelia. Thus, phorids after spawning and casing are quite vulnerable for phorid invasion.

Control measures are similar to those of the sciarid fly.

Cecids

The adult cecid fly (*Mycophilla speyeri* or *Heteropeza pygmaea*) is not often seen by growers but the larval stage is the most destructive. The adult fly is usually less than 1 mm long. The lack of venation in the wing makes the adult very distinctive from the other fly species (Figure 23). The cecid larvae are usually 2 to 3 mm in length and orange in color. After hatching, the larvae begin feeding on mycelia and within six to seven days, 10 to 12 daughter larvae rupture the body of the mother and begin to feed on the mycelia. The direct production of offspring without copulation is known as larval paedogenesis and can result in a logarithmic growth in population. The larvae are responsible for spreading bacterial diseases as well as feeding on the mushroom stems, caps and mycelia. Large populations will result in obvious contamination of processed mushrooms. Control measures are essentially the same as those used for sciarid or phorid flies. An infestation which occurs within two weeks of spawning can result in populations of 200,000/m² if left unchecked.



CECID FLY

Figure 23. Cecid fly

Mites

Several species of mites cause problems in mushroom production. The mites are most commonly associated with the weed molds which act as their food source. The most obvious is the red pepper mite which swarms in large numbers on the casing and mushroom caps. These do not feed on the mushroom but act as a contaminant to the processed product. Most mites cannot be seen by the naked eye but those of the *Tyrophagus* genus have been found to feed on mushrooms and cause small regular pits in stalks and caps.

An infestation of mites can usually be related to a poor Phase II and the later development of competitive weed molds. Mites are relatively resistant to the insecticides used for fly control. Specialized miticides are used in Europe to obtain control but none of these materials can be used in Canada without registration. Sanitation and proper Phase II (58 to 60°C for 4 hours in the beds) are currently the only

control mechanisms. The generation time is reduced at high temperatures, therefore mites are often more of a problem during the summer.

Nematodes

There are two distinctive types of nematodes found in mushroom houses (Figure 24). The fungus feeding or stylet bearing nematode (eelworm) can feed directly on mushroom mycelium by penetrating the cell wall and draining the contents. In over 3000 samples examined at the research station at Vineland, none of this type of nematode has been found. However, large numbers of saprophagous nematodes have been counted. These have sucking mouthparts which are incapable of piercing mushroom mycelium. These nematodes feed on bacteria or non-living matter in the compost and casing. Saprophagous nematodes can be considered as an indicator that some segment of the production cycle was performed incorrectly. High populations can be associated with wet compost or a slimy layer between the casing and the compost. These nematodes will only move in water films, creating dry conditions in the mushroom house will slow their development. The species of saprophagous nematodes found in Canada do not form a resting stage and can therefore be eradicated by a proper Phase II and good sanitation.

Saprophagous nematodes may cause reduction in yield and quality. Typical symptoms may be slow mycelial growth into casing, poor or spotty pinning, a drop in production or quality. Certain factors tend to favor nematode multiplication and subsequent damage. There is greater multiplication in unspawned compost than in casing soil. Off-white strains are less tolerant to nematodes than white strains. Watering at spawning favors population increases. Ruffling the casing tends to stimulate multiplication. Nematodes multiply more rapidly in younger spawn-run than a mature spawn-run. A safe situation is provided through adequate sanitation and Phase II, a mature spawn-run, white strains, avoiding over-watering and insect control.

Diseases

The following is not intended to be a detailed description of all diseases of the mushroom crop, but rather an outline of the most common problems and their potential control.

Verticillium

Verticillium or dry bubble (*Verticillium fungicola*) has three characteristic symptoms. The first is a light brown spotting of the cap. As the spots enlarge they coalesce. A mass of spores in the center of the spots will cause a grey bloom to develop. If infection occurs just as the pinhead is developing (the second symptom), a malformed mass of tissue which is dried and greyish in appearance will result. The third symptom is abnormal swelling of the stipe or a downward peeling if infection occurs on the side of the stem (Figure 25). Infection on the side of an enlarging cap will cause a harelip type of cleft to develop. The disease can be spread by water, mites, flies and workers. Sanitation is critical since dusts and sprays offer only a limited degree of control. The use of benomyl and zineb can be alternated to achieve more effective control. Diseased mushrooms should be removed from the beds prior to watering or disease spread will be enhanced.



Figure 24. A comparison of a saprophagous (left) and fungus feeding (right) nematode. Note the lack of spear in the buccal cavity (a) of the saprophagous nematode. (H.H. Lyon, Reproduced from Pictorial Key to Genera of Plant Parasitic Nematodes by Mai)



Figure 25. Typical symptoms of verticillium showing the downward peeling of the stipe and the cleft on the side (Vedder)

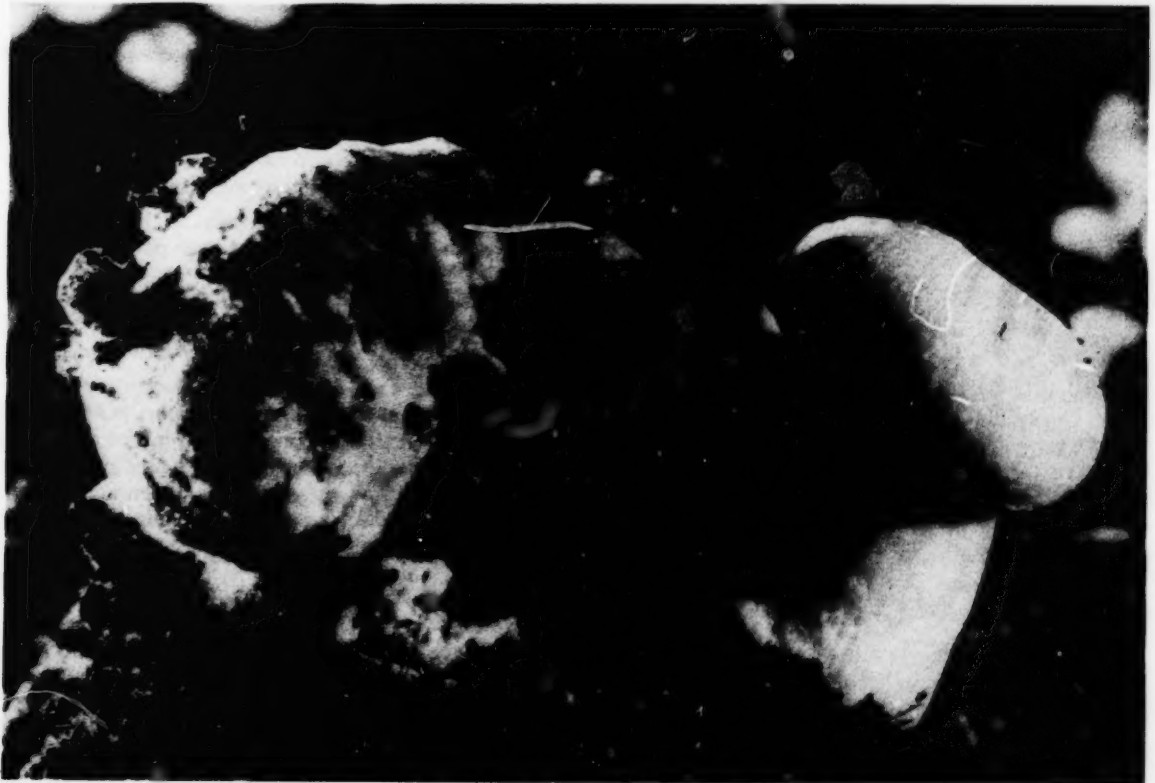


Figure 26. Wet Bubble disease displaying the fluid exudation which gives the name to the disorder (Vedder)

Wet Bubble

Wet bubble or *Mycogone* (*Mycogone perniciosus*) is a mold which develops as a white, felt-like growth of mycelia on the mushroom. It can spread over the entire mushroom and then penetrate into the tissue. This results in a white, soft, foul-smelling mass which exudes drops of amber fluid (Figure 26). If the mushroom is attacked before pinhead development it will grow as a mass of undefined shape. Fungicides applied at the time of casing have provided good control but if the disease occurs during cropping it is difficult to bring it into check. Water promotes the spread of the disease. Thus liquid applications of chemicals help disperse the spores even further. Flies are a very effective carrier of the disease spores, and a combination of these two pests can have disastrous results.

Bacterial Blotch and Pit

There are several bacterial disorders of the mushroom crop. The most common symptoms are bacterial blotch and pit which is caused by a species of *Pseudomonas*. Blotch is characterized by circular or irregular yellowish spots on the cap which enlarge to form chocolate brown slight depressions (Figure 27). The infection penetrates only 1 to 3 mm. The pit disorder results in small holes in the surface of the cap (Figure 28). The holes or pits contain glistening slime which harbours the bacteria. The pit is thought to be secondary to rupture of the mushroom cells by irregular watering. Both diseases may be held in check by using chlorine at 150 to 200 ppm in the regular watering. However, any conditions which cause the mushroom caps to stay moist for extended periods of time will promote bacterial diseases. Stagnant, moist air with a temperature above 15 to 16°C and changes in temperature which cause moisture to condense on the mushroom predispose the crop to attack by these disorders.

Mummy

The causal organism of mummy has not been conclusively identified but is assumed to be bacterial. The first sign of mummy is that areas of a bed are retarded in development. Mushrooms in these areas grow more slowly and display a thick base surrounded by a profuse growth of white mycelia. The stipe is elongated, slightly crooked and the cap is tilted (Figure 29). The mature mushrooms do not rot but dry out, become leathery and appear mummified. When cut, the stipe often turns reddish brown. When the mushroom is pulled from the bed, more mycelium than usual adheres to the base. This is in contrast with virus-infected mushrooms which are usually loose on the beds. The disease can spread radially at 30 cm per day and no totally effective control is known. Some growers report success at stopping the spread of the disease by digging trenches in the compost. The trench should be cut 2 m in front of the advancing edge of the disease to prevent any direct contact between healthy and infected mycelia. The trench can be dusted with salt or chlorine. There are some indications that a high moisture content in the compost or the casing layer coupled with excessive humidity will promote the disorder.

Virus

Virus is often suggested as the cause of a poor crop. Part of the reason is that there are many different symptoms which are produced by virus infections and it is difficult to prove exactly whether a virus has caused the problem. Mushrooms, as with many other forms of life, have a latent virus infection. Special techniques have produced "virus-free" fruit trees, etc. but this method cannot be used effectively in mushroom culture. Some researchers have indicated that virus-like particles have been found in every sample examined. If we assume that virus is always present then

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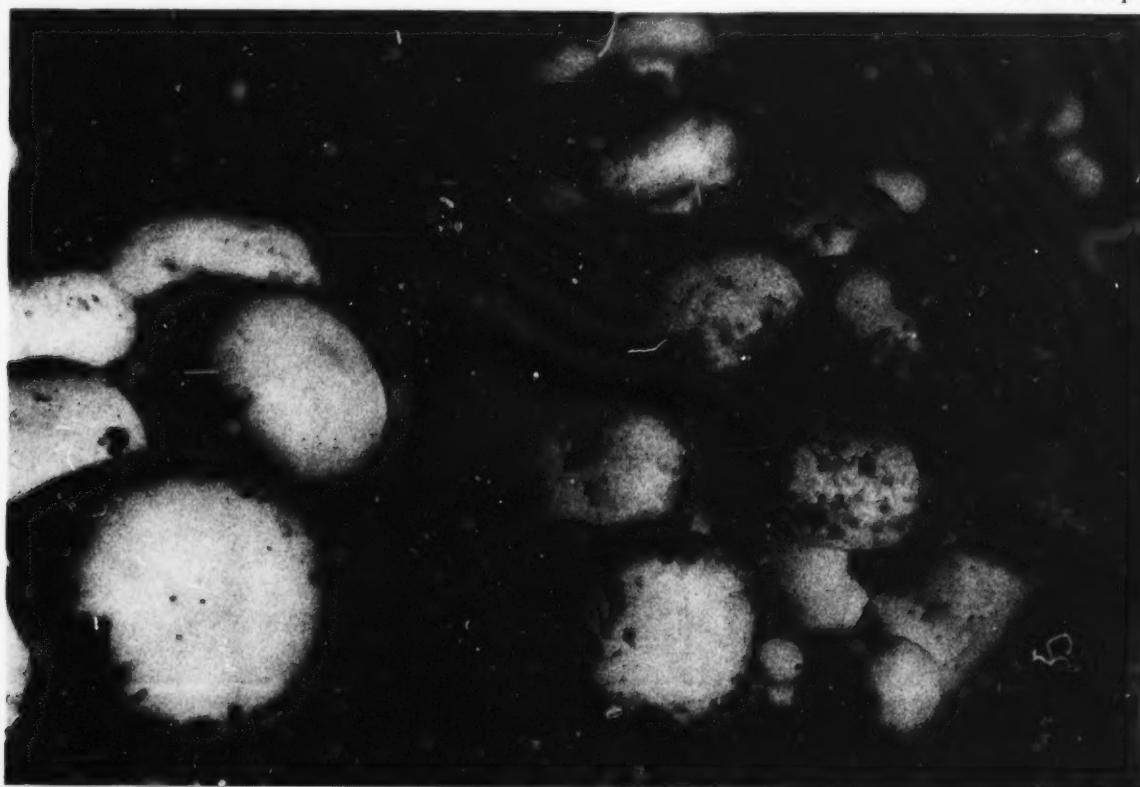


Figure 27. Bacterial blotch-infected mushrooms (Vedder)



Figure 28. Bacterial pit on mushroom caps (Vedder)



Figure 29. Elongated and crooked stipe, tilted cap and mycelial growth at the base of the stipe are symptoms of the mummy disease (Vedder).

Continued from page 21

knowledge of the factors which allow for the manifestation of the symptoms should aid in limiting the spread of the disease. Virus particles must have a carrier which most often is the mushroom spore. The infected spores can be spread by wind or water or carried by insects. The disease can also be spread in the compost where anastomosis of the mycelia occurs. This joining of the mycelia allows the transfer of the virus from one strand to another.

The typical symptoms of virus are drumstick-shaped and elongated stems, premature opening of the caps, and often bare spots on the beds. Areas of the compost may have little or no mycelia as a result of the "dieback" symptom often associated with virus. The amount of virus in the crop directly affects the severity of the disease which can vary from symptomless to complete crop failure. Virus symptoms are often associated with an improper balance of nutrients which in turn may enhance virus development relative to the mushroom growth. A change in mushroom strain, with its different specific nutrient requirements, may sometimes prove to be a good decision. However, when virus symptoms are observed, a critical assessment of the compost composition and providing optimal conditions for composting may help to solve the problem. All mushrooms should be picked before the cap is open to prevent spore dispersal. There is some suggestion that heavier spawning rates and shorter cropping will reduce the severity of infection. Evidence indicates that *Agaricus bitorquis* is more tolerant to attack by virus than *Agaricus brunnescens*, and rotating this mushroom into the production cycle may reduce losses.

Other Disorders

Rosecomb is a malformation of the mushroom due to a pollutant with symptoms similar to an early infection of wet bubble. The causes of rosecomb are the gases and vapor from heating equipment, fuel oil, or carriers in certain pesticide formulations. Some pesticides when applied improperly will result in distorted mushrooms.

Uneven casing, excessive temperatures or high relative humidity combined with insufficient ventilation may cause overlay. This disorder is characterized by excessive mycelial growth on the surface of the casing so that a mat of mycelia is produced. Damage can be reduced by loosening the casing soil and ventilating the house.

Many colorful molds will grow on the surface of the compost. These molds are usually regarded as indicators that some part of the composting process was inadequate. They can usually be related to a poor Phase II. An improper Phase II will allow the growth of these competitive molds rather than promote normal mycelial development. Lipstick, brown mold, yellow mold and green mold are all examples.

Structural Systems

The bed and the tray system are the two most commonly used systems in the mushroom industry. The basic difference is the mobility of the compost to be transferred from one room to another. With a tray system, the compost is filled in special trays which are stacked in a cook-out room. After the cook-out, the compost is spawned and transferred to a spawning room. After spawning has taken place, the casing is applied and the trays are stacked at the final spacing in the cropping room. Filling, spawning and casing the trays are handled by specialized machinery. Each room is equipped to maintain a specific climatic environment. The stacked trays are moved by means of forklift trucks. This highly mechanized system is often referred to as a multiple climate system or a multiple "zone" system, and is popular in England. With a bed system (one-zone), one single room

containing a few rows of stacked beds is used for cook-out, spawning, casing and cropping without the compost being removed until emptying. This is the most common system used especially by smaller growers all over the world. The houses are built in many different ways such as bamboo combined with palm and banana leaves, multilayered polyethylene houses, brick and concrete blocks or other synthetic materials.

Recently the concept of mass pasteurization has become more widely accepted. With this concept, compost is pasteurized in large well-insulated containers. The containers, also called "tunnels", are used for the spawn-run. After the two initial stages, which take place in bulk, the compost is transferred in a hygienic manner to beds in which filling and casing of spawn-run compost take place. This method overcomes some of the disadvantages of the tray system and adds considerable improvement to the bed system. The beds can be used more intensively than before, while the cook-out can take place more uniformly and efficiently resulting in less dry-matter loss of the compost. (For more detailed information see section on "tunnels".)

Typical Ontario Mushroom Houses

The following is a general description of how mushroom houses have been built for many years. They have been constructed almost exclusively of blocks. The windowless rooms are approximately 21 m long and 6 m wide. They contain two vertical columns of beds 1.35 to 1.80 m wide with a center aisle of 1.20 m and two perimeter alleys of 0.75 m. The beds have approximately 15 to 20 cm sideboards and are stacked 5, 6, 7, 9, or sometimes even 12 high with a catwalk at every third or fourth bed. A typical room has two rows of beds, six stacks high, 1.65 m wide, 18 m long, each bed being supported by two rows of upright posts (Figure 30). The posts are 1.20 m apart, and placed on the floor. They support a false wooden ceiling which is usually slightly arched. The floor is generally made of concrete and is sloped to allow excessive moisture to flow to a predetermined spot in the room where it is allowed to drain away.

The total growing area of a house (21 m × 6 m; 6 beds high) is about 360 m² and is called a "single". A "double" is twice the size of a "single" in width, having four rows of beds and 720 m² of growing surface. Few doubles are found in Ontario.

If building in hilly terrain, the hill is often terraced. The mushroom houses would then be built in such a way that on one side the catwalk is level with the higher ground level, while the bottom floor is level with the lower level of the

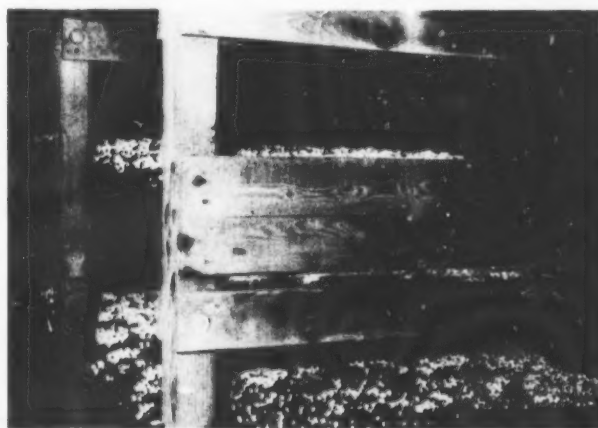


Figure 30. Close-up of standard bed construction showing the double row of support posts

terrace. Filling the houses is done from the higher level. This level is also used to position the air-conditioning equipment during the summer.

It is practical to have all the rooms connecting to a central hallway. This will provide some additional working space for spray equipment, wagons and other supplies. This hallway should be at least 4.5 to 6.0 m wide. A stairway leading to the catwalk is located at the end of a room and near the hallway. When selecting a site, one should also consider the quality of the water source. High soluble salt levels (greater than 1.0 milliSiemens/cm) in water may have harmful effects on the growth of mushrooms.

Construction Materials

Although no specific standard plans exist for mushroom houses, some guidelines can be given. Firstly, it is advisable to have well-insulated walls and ceilings in the rooms. Good insulation will allow easier maintenance of the required environment and will also keep the energy costs down. An estimated 50 to 100 litres of oil per square metre of growing area per year is used in standard houses with year-round production. An insulation value (R) of at least 10 is recommended for the walls between the rooms. An even higher value for exterior walls is preferred. Blocks filled with an insulating material are often used for this purpose, even though they represent a significantly lower R value than 10. Sandwiched aluminum polystyrene or polyurethane panels have better insulating properties but are also more expensive. Damp-tight walls will reduce moisture loss and are preferred. Most mushroom houses have a peaked roof with a false ceiling. Insulation material in the form of cellulose, glass wool, zonolite (vermiculite), or fiberglass is added to the top of the false ceiling in order to prevent dripping of condensate and thus an excessive heat loss. A vapor barrier such as polyethylene is usually placed between the false ceiling and the insulating material. Insulating the floor is not normally done but should be considered.

Construction materials for the beds have to be capable of withstanding high temperatures (up to 70°C), a high relative humidity (80 to 100%) and high levels of ammonia. Wood such as hemlock, cedar, and redwoods can be used. Wood such as spruce or pine is less expensive but will not last as long as the previously mentioned types. Hemlock seems to be the most effective material for Ontario growers.

Nails, screws and bolts needed to construct the beds have to be hot-bath galvanized. Galvanized steel is often used in the construction of the beds as well. However, some woods will deteriorate very quickly upon direct contact with galvanized steel. Certain kinds of aluminum can also be used especially as sideboards.



Figure 31. Filling compost onto a net. When the crop is terminated the net is rolled up for ease of compost removal.



Figure 32. Large doors which can be removed to facilitate filling and emptying a room

The exact dimensions of the beds as well as the construction may depend on whether the intent is to use a net system to mechanically fill and empty beds (Figure 31). The nets are available in a limited number of sizes and the inside measurements of the beds should be a bit narrower than the width of the nets. Moreover, the sideboards which are attached to the uprights should allow a space of 1 to 2 cm between the bottom boards and the sideboards. This makes it possible for the nets to be pulled under the sideboards. Sufficient working space at either end of the beds for the pulling machines as well as the filling mechanisms must be provided. In most older houses there is insufficient space for these machines. A space of 2.0 to 2.5 m should be allowed on either end. When nets are not used the sideboards are not fixed permanently to the uprights. The bottom boards of the beds are spaced about 2.5 cm apart so air can enter the compost.

Doors have usually been built relatively small (1.20 × 2.40 m). Consideration should be given to bigger, insulated doors to provide sufficient area to facilitate filling and emptying the houses (Figure 32). This has become more important now that many growers are adopting the use of nets. The big doors are required only on the filling and emptying side of the house. These larger doors would eliminate the need for some of the cross conveyors presently used. A small door on the opposite end of the room (usually the central hallway end) should provide sufficient passage for both pickers and the crop.

Heating and Ventilation Requirements

Heating of the houses can be done in many different ways, the most common being galvanized hot waterlines on the perimeter. A steam boiler is required for cook-out and steaming off the crop. Hot water is supplied either with a heat exchanger with the steam boiler or a separate hot water boiler.

In most of the older mushroom houses, ventilation takes place through vents which are located in the false ceiling of the house. These vents are 2.5 cm thick and 30 cm wide boards running the entire length of the room in sections of about 3.0 to 4.5 m in length. They are opened or closed manually by means of a cord, which runs over a pulley connected to a truss in the roof. It should be noted that the attic between the false ceiling and the roof usually runs across a number of rooms and is ventilated by means of ventilating shafts. The open connection in the ceiling does

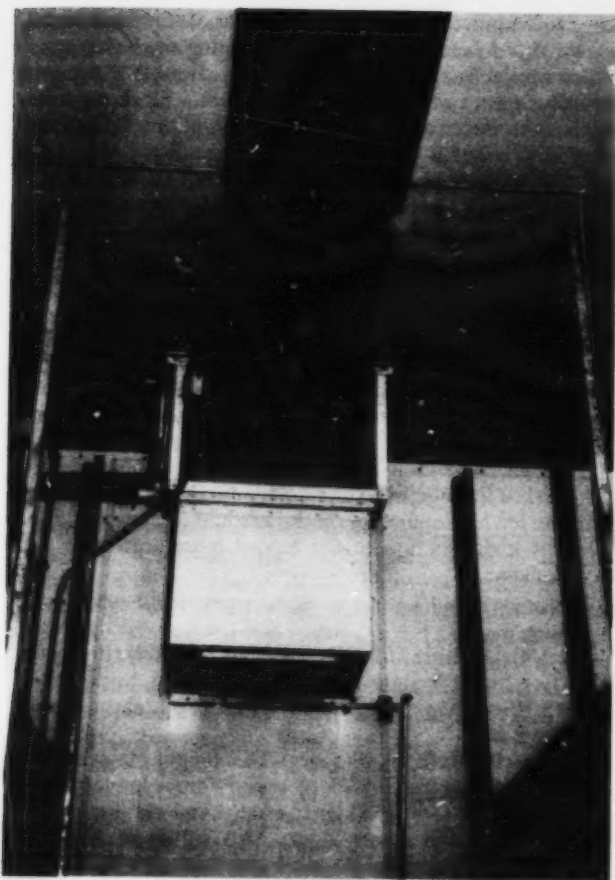


Figure 33. Air circulation system for interior of a mushroom house

not provide any safeguard against disease spread. Air movement within the houses is usually provided by one or two movable open-ended fans situated on the floor and/or catwalk. Circulation by means of a fanjet system has become very popular (Figure 33). Air is forced through a polyethylene, wood or aluminum duct system by means of an electric fan. The air duct is suspended from the ceiling and has openings to allow the air to escape. A provision to allow for mixing outside air with the recirculating air is very rarely seen.

Newer and retrofit houses are usually equipped for improved environmental control. This means that vents in the roof are omitted and circulation and ventilation combined with heating and/or cooling are practiced with an air-handling system. This unit basically consists of a fan with a cooling and heating unit in series connected to a duct system for distribution within the house (Figure 34). A special louver at the intake side of the fan regulates the amount of fresh air and inside air to be recirculated. This mixture is then either cooled or heated depending on its temperature, relative humidity and the requirements of the crop. For cooling requirements see the section on air-conditioning.

A centrifugal, variable-speed fan is preferred to a blade-type fan, since the volume of air moved is not as dependent on the static pressure in the room. Variable-speed ventilators are expensive and, as an alternative, an intermittent on/off system with a single-speed ventilator can be installed in order to move the required amount of air per hour. A time clock which starts and stops the ventilator every so often is less expensive. The fan size should have a capacity to

circulate about 15 to 20 m³ of air per square metre of bed surface per hour. With a ratio of air volume (m³) and bed surface (m²) of about 1.5 to 1.6, this provides a moderate airflow along the beds. Extremely high air velocities should be avoided especially under conditions of low relative humidity to prevent scaling of the mushrooms. The relative humidity can be increased by the use of a small steam line in the air duct, a misting system or wetting the floors and walls of the rooms.

In the foregoing situation, a positive air pressure will be obtained in the room. A pressure of about 6 to 10 mm water column is sufficient to prevent any mushroom flies from flying into the room. (However, the insects can crawl against this pressure.) A louver system at the other end of the room will allow excessive air to escape. Air filters with a small pore size (0.5 to 1.0 microns) placed at the entrance of the fresh-air inlet will prevent undesirable spores or flies from entering the room. Peaked and ventilated roofs will become unnecessary, but flat roofs need sufficient insulation to prevent moisture dripping onto the beds.

A step to further increase efficiency is to use a centralized air-handling system. At a central location, outside air is filtered and conditioned to about 13 to 15°C at 90 to 95% relative humidity and held at a small positive pressure. Each room is connected to this supply with the aid of a network of ducts positioned in the central hallway. In addition, each room should have a separate air-handling unit as previously described, e.g., a fan connected to the central distribution network. The cooling coils are fed with the cooling liquid from a central compressor rather than having large units for each individual house. The capacity of the heating coils,

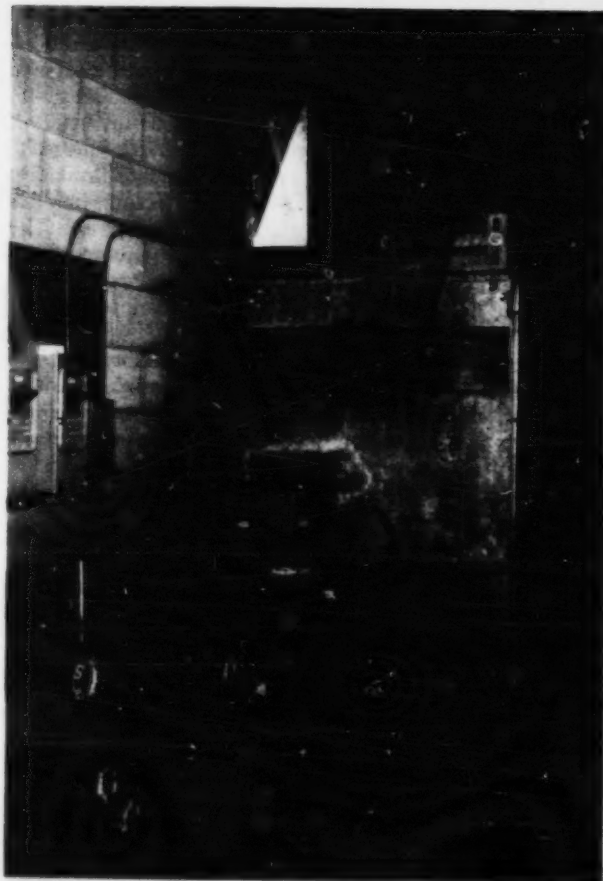


Figure 34. An air-handling system which allows for temperature regulation and air circulation

which are fed by the boiler, depends on the perimeter heating and vice versa. In well-insulated rooms the need for perimeter heating may become minimal.

Tunnels

Since 1975, bulk pasteurization and bulk spawn run have become a rapidly expanding development in the mushroom industry. Bulk pasteurization enables the grower to perform a cook-out in a more controlled environment since the temperature throughout the compost is usually within 1°C due to the use of forced air. This results in a better finished product and hopefully a lower loss in dry-matter content of the compost. Bulk spawn-run can take place in similar tunnels after which beds, bags and/or trays can be filled and cased. Moreover it has proven to be a technique in which considerable amounts of energy can be saved.

Mass pasteurization takes place in well-insulated tunnels fitted with a double floor and an adequate ventilator for air movement (Figure 35). Temperature control takes place by a thermostat and by means of a damper regulating the amount of circulating and incoming fresh air. The tunnel has a false slotted floor on which the compost is stacked (Figure 36). Air is forced between the two floors and pushed through the compost from the bottom up. The air mass, which is forced evenly throughout the compost if properly stacked, is collected on top of the compost and mixed with fresh air or recirculated by the ventilator. The ventilator is positioned at one end of the tunnel, while doors at the opposite end allow filling and emptying. A steam inlet between the two floors is needed to provide heat for pasteurization and possible addition of moisture.

The walls and the roof of the tunnels should be well insulated, an R-value of 15.0 to 20.0 for Ontario conditions seems appropriate. Sufficient insulation is necessary to prevent cooler areas near the walls and consequently an improper cook-out or uneven spawn runs. Walls made of aluminum or polyester sandwich panels, filled with polyurethane or polystyrene, will provide adequate insulation when applied at sufficient thickness (10 to 15 cm). The walls should be made airtight to prevent any moisture losses. The false floor can be made of wood or concrete segments. A removable floor will make cleaning of the bottom floor easier. The bottom floor should also be equipped with a drainage outlet which can be sealed off.

The ventilator should have sufficient capacity to move 150 to 200 m³ of air per tonne (t) of compost per hour with a static pressure of 20 to 150 mm water column. A centrifugal type of ventilator is recommended. The static pressure will

have to be increased during the course of the cook-out or spawn run due to the natural compacting of the compost which results in a higher resistance to airflow. A damper in the return duct of the ventilator will allow fresh air to be mixed with the circulating air. The fresh-air inlet should be filtered to prevent entrance of any undesirable organisms into the room. For a spawn-run tunnel, air-conditioning is also necessary to prevent overheating. Care should be taken so that the air inlet is not positioned near any source of contamination such as diesel or gas engines.

Both filling and emptying of tunnels are done with a nylon net system. The strength of the required nets depends on whether or not a glider net is used and the length of the tunnel. The filling procedure has to be carried out very carefully, since a uniform compost pile in the tunnel is of utmost importance to provide for an even airflow throughout the pile.

The basic dimensions according to Vedder (see Suggestions for Further Reading) are 5.0 m high and 3.0 to 4.0 m wide, with the length depending on the amount of compost to be filled. A cross section of the tunnel from bottom to top would show:

- a floor with a 1% slope to allow excess moisture to drain away;
- at 0.50 m a slotted false floor so that 25% of the floor area is free for airflow and 75% is for supporting the compost;
- at 2.30 to 2.50 m the top of the compost pile at the time of filling;
- at 2.50 to 4.0 m an air space. This height may vary but there should be sufficient space for a louver to be installed for the excess air to escape and also for louvers leading to the return duct. Also sufficient height is needed for equipment such as conveyor belts and tractor.
- at 4.0 to 5.0 m a roof filled with at least 0.40 m of insulating material.

For calculating the required length of a tunnel, it has been shown that a compost depth of about 2.0 metres at filling time seems optimum. Thicker layers should be avoided due to possible compaction problems and thus anaerobic conditions. One cubic metre of fresh compost weighs approximately 400 kg. This means that at filling, the compost in one square metre of tunnel at 2.0 m high will weigh about 800 kg. During the cook-out there will be a total weight loss in the compost of 20 to 30% and a further 5 to 10% will be lost during the spawn run. Therefore the spawn-run tunnels can be made 20% smaller than the cook-out rooms. If the amount of compost required for a particular mushroom



Figure 35. Interior view of empty tunnel with a filling net in the foreground



Figure 36. Slotted floor of the tunnel

production house is known, then the size of the cook-out tunnels and spawn-run tunnels can be calculated by using the above figures. For example, if 50 t of compost are required to fill a room, the following calculations can be made: $50 \text{ t} + 10\% \text{ (spawn-run loss)} = 55 \text{ t} + 30\% \text{ (Phase II loss)} = 71.5 \text{ t}$ of compost at the time of filling. (N.B. Up to 30% shrinkage may occur during Phase I.) Each tonne requires 1.2 m^2 in the tunnel, therefore 85.8 m^2 or a room $4 \text{ m} \times 22 \text{ m}$ is required.

A provision should be made to transport spawn-run compost to the growing room in such a way that chances for contamination are kept to a minimum. Transportable feed wagons are commonly used for this purpose. A wide covered hall on the filling side of the production houses will allow easier handling especially during the cold winter periods when transferring the spawned compost to the production houses.

Air-Conditioning

Air-conditioning has enabled growers to produce mushrooms on a regular basis during periods when outside temperatures are above 22°C . This was not a general practice before the seventies. Many smaller growers kept their houses empty for two to three months after a thorough cleaning early in the summer. This sanitary practice assisted growers in controlling severe outbreaks of insects around the plant as well as serious diseases such as *Verticillium*, *Mycogone*, mummy, etc. which are more likely to spread during the summer. With a move to more intensified mushroom farming, the use of air-conditioning has become a must. During spawning, casing and cropping, cooling of the air is necessary throughout the summer period. A sample calculation will be given to estimate the capacity of the air-conditioning system under Ontario climatic conditions for a standard 360 m^2 room built with 20 cm concrete block side walls and a well-insulated ceiling.

During the production period an air temperature of about 16 to 18°C and a relative humidity of approximately 85 to 90% are desired. An elaborate system with cooling, heating and misting components is needed to fulfill both conditions. Many growers have air-conditioning units which are primarily used to cool the air without controlling the relative humidity. For the following calculations the relative humidity will be partially ignored.

The sources of heat in a mushroom house during the summer can be divided into four categories:

- (A) **Walls.** This is primarily a conductive heat flow through the walls, floor and roof of the room. The extent depends on the temperature gradient between inside and outside the insulative properties of the surrounding walls.
- (B) **Ventilation.** The amount of fresh air needed for crop production as well as the outside temperature conditions determine this factor.
- (C) **Heat production from the beds.** When mycelia and mushrooms grow, carbohydrates are metabolized and consequently CO_2 and heat are produced. Alternately, normal evaporation from the mushrooms will cool down the beds and must be included in any calculations.
- (D) **Miscellaneous.** Includes all heat produced by lights, motors, workers, heat vaporized from walls and floors and bringing the irrigation water to room temperature. For practical purposes these factors can be ignored.

Calculation for Cooling Requirements

Wall Load

For calculation purposes, assume a room with 360 m^2 of bed surface and the dimensions of approximately $24.0 \times 5.5 \times 5.0 \text{ m}$. The overall heat transfer coefficient (U) for 20-cm concrete block walls is $18.5 \text{ kJ/m}^2\text{-h}^\circ\text{C}$. The two end walls (ignoring the sidewalls) have a total surface area of 55.0 m^2 . The design temperature for the Toronto-Hamilton area during July and August is 31°C . With an inside air temperature to be maintained at 15°C ($T = 31 - 15 = 16^\circ\text{C}$), the total heat gained can be calculated by the following formula:

$$Q = \text{heat transfer coef.} \times \text{surface area} \times \text{temperature gradient} \\ = 18.5 \times 55 \times 16 = 16280 \text{ kJ/h.}$$

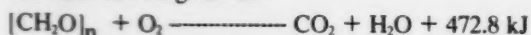
Ventilation Load

The ventilation requirement for a 360 m^2 house depends on the rate of CO_2 production. The bed temperature and the yield per flush are the two main factors determining the CO_2 production.

At 15 to 16°C air temperature and a fill of 100 kg of compost per square metre, a CO_2 production of one gram per hour may be expected for each kilogram of mushrooms on the beds. This guideline may be used for the first three flushes with a 20% increase for each degree Celsius increase in bed temperature. This means that, for a standard house (360 m^2) with a flush yielding 5 kg/m^2 , 5 m^3 of air per m^2 bed surface per hour is needed to maintain the desired level. As a rule of thumb, one cubic metre of fresh air per hour is needed for each kilogram of mushrooms at a normal fill and at 15 to 16°C . During July and August, with the maximum design temperature of 31°C and a relative humidity of 55%, this volume of air has to be cooled down. The amount of heat which has to be extracted to cool one cubic metre of air with a temperature of 31°C and 55% relative humidity is 33.3 kJ/m^3 or $59.9 \times 10^3 \text{ kJ/h}$ per house. For later flushes this may be approximately one-half.

Heat from Cropping Area

A simplified equation to represent the source of heat from the beds can be given as:



Carbohydrates + Oxygen $\longrightarrow$ Carbon Dioxide + Water + Heat

Taking the value for CO_2 production from the above paragraph it can be calculated that about $1800/44 \times 472.8 \text{ kJ/j}$, or $19,341 \text{ kJ/h}$, of heat is produced in a 360 m^2 house during the first three flushes.

Moisture needed for the mushrooms to grow is taken up from the compost and most of the water which is applied to the casing layer is evaporated. A general rule is that one litre of water must be applied to the beds for each kilogram of mushrooms. This would mean that 1800 L of water per house has to be applied for a flush of 5 kg of mushrooms per m^2 . The heat of vaporization for water is 2270 kJ/kg . Assuming that evaporation of this water takes place at a constant rate during the period of a flush (seven days), then the cooling rate can be calculated as being $(1800 \times 2270 \text{ kJ})/7 \times 24$ or $24.3 \times 10^3 \text{ kJ/h}$.

The total amount of heat which has to be dissipated under the above circumstances for a 360 m^2 house would be: $15,985 + 59,900 + 19,341 - 24,300 = 70,926 \text{ kJ/h}$ or $70,000 \text{ kJ/h}$ of refrigeration per house (Table 3). This figure can be considered to be the maximum capacity needed for cooling during the production cycle. It should be noted that the refrigeration load due to ventilation is the most important factor with the bed effect almost negligible.

Table 3. Air-conditioning requirements for a standard single house*

Factor	kJ/h
Transfer through walls	15,985
Ventilation air	59,900
Growing mushrooms	19,341
Water evaporation from beds	-24,300
TOTAL	70,926

*Assume outside temperature of 31°C, relative humidity 55% and a crop of 5 kg/m². Details of calculations are given in text.

Heat flow from neighboring houses and outside walls has been omitted in this calculation. Moreover it has been assumed that ventilation is at a constant rate during a 24-hour period. Growers have cut corners by ventilating at night and primarily circulating during the daytime. This

practice may help under extreme conditions but should be avoided if possible.

During spawn-run, when ventilation can be kept to a minimum to maintain high CO₂ levels, the refrigeration load is considerably less.

It should also be remembered that refrigeration units do not control the relative humidity. Under Ontario conditions with an air temperature of 31°C and a relative humidity of 55%, the relative humidity of the air coming through a refrigeration unit will be close to 100%. To lower the relative humidity of the ventilation air, a combination of refrigeration in series with a heating coil can be installed. The incoming air has to be cooled even further after which it can be slightly heated to achieve the required relative humidity.

II. CULTIVATION OF OYSTER MUSHROOMS

The oyster mushroom (*Pleurotus ostreatus*) is a wood-decaying, saprophytic fungus. It can be found in temperate zones and is native to Ontario.

The genus *Pleurotus* is characterized (Figure 37) by the eccentric or lateral stipe or lacking stipes altogether. The gills are white to pallid and often fuse together where they extend down the stipe. The pileus may grow 5-15 cm and is of gray, gray-brown, or slate-gray color. The whole fruiting body is soft and fleshy.



Figure 37. *Pleurotus* mushrooms showing characteristic shell-shaped cap with the stem attached in off-centered fashion

Preparation of Substrate

Many kinds of organic material are suitable for the preparation of a substrate. Initially, the oyster mushroom was cultivated on wood stumps and logs. During the late 1950's production began on sawdust, mushroom compost or grain straw. Good results have been obtained from wheat straw, although rye or barley may be used. It is preferred that the straws be crushed and cut into pieces. This provides

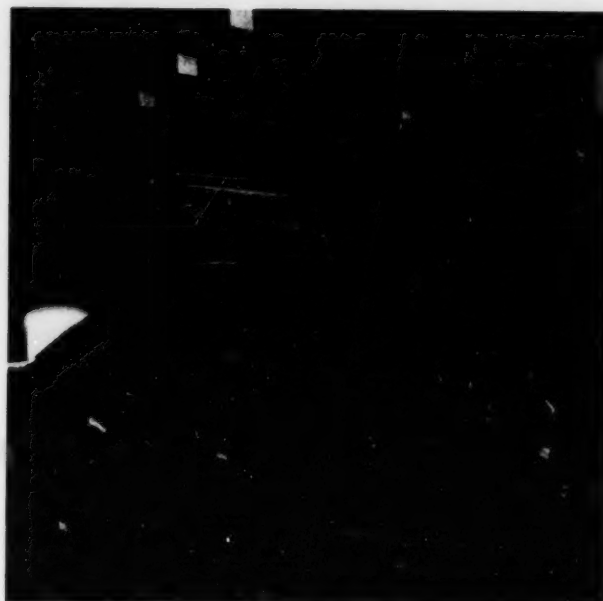


Figure 38. Wheat straw with corncob additive stacked in a pile



Figure 39. Pasteurized substrate being removed from a tunnel

for easier handling and a quicker water uptake by the dry straws. Corncobs, grass meal or alfalfa meal may be added at a ratio of 10-20% of the dry weight of the straw.

The final substrate requires that the inbound moisture be at least 72%. In order to increase the initial moisture from 15% approximately 3000 L of water must be added to 1 ton of straw. This process requires about 4 days. During the first day about 1000 L of water may be added to the crushed and cut straws. On the second and third day, the straw is mixed and turned and the additional water added. On the fourth day, the additives are spread over the straw and mixed well. The straw can then be stacked in a pile (Figure 38). On the following day, the compost should be ready for pasteurization. The compost is ready when (1) the straw colour is yellow-brown, (2) the moisture is about 75-78%, (3) the compost pile temperature is between 40-45°C, and (4) the straw is rather stiff and barely composted.

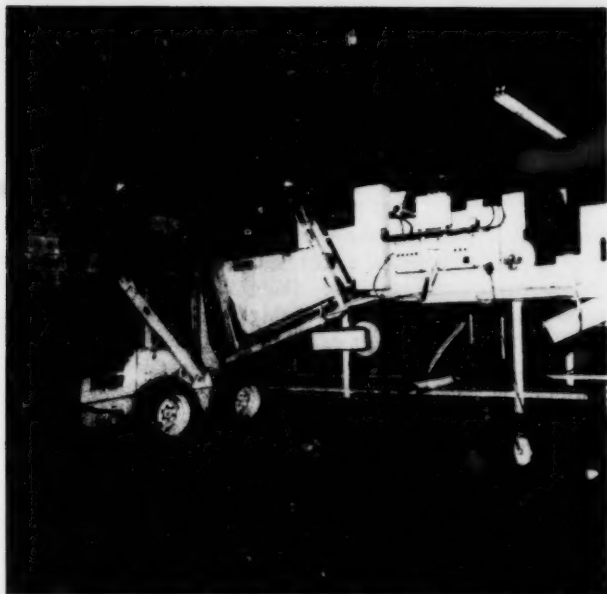


Figure 40. Pasteurized substrate being placed into filling machine



Figure 41. Pasteurized substrate moving onto bed or shelf in production room

Filling, Pasteurization and Conditioning

The compost can be filled into standard bed shelves, special trays, or in bulk in tunnels for pasteurization and conditioning (Figure 35). Uniformity of filling is important to avoid temperature differences during pasteurization and conditioning.

Pasteurization is required to kill pathogenic organisms. In practice, researchers and growers have pre-conditioned for 0-48 hr. at 50-55°C, pasteurized for 4-72 hr. at 60-70°C followed by a conditioning period of 24-48 hr. at 50-55°C. Total time required is 3-5 days. After pasteurization the substrate should have the following properties: (1) the moisture content is 70-72%; (2) straws are light brown in color; (3) straws are no longer brittle; and (4) the volume of substrate has decreased.

Spawning

There are a number of strains of the oyster mushroom available commercially. They are divided into two basic types — the European or winter types which require temperatures of 10-15°C to fruit and form mushrooms, and the summer or Florida types which fruit at 18-23°C. The winter types produce mushrooms that are usually slate-gray and have a more woody texture than the cream or light-brown ones characteristic of the Florida types.

After pasteurization the substrate is spawned by machine (Figure 13) or by hand and is filled into bags, trays or beds (Figures 39-41).

The amount of spawn varies from 1 to 4% of the wet weight of the substrate (Figure 12). A higher spawn rate will have a more rapid mycelial growth but may cause higher temperatures than desired in the trays, bags, or beds. Spawn is distributed uniformly throughout the compost as the spawning procedure occurs.

During the spawn-run the compost temperature is maintained at 24-26°C at a relative humidity of 90-95%. High CO₂ levels are desirable for optimum growth of the mycelia, so minimum exterior ventilation is required. However, intensive internal circulation in the growing room is required to



Figure 42. Well-colonized substrate before pin formation

prevent temperature difference in the substrate. It takes about 14-20 days to colonize the substrate. Pinning should not be initiated before the substrate is completely white (Figure 42).

Pin Formation

To initiate formation of pins, the compost temperature is cooled to 10-18°C, depending on the strain being grown. Fresh air is introduced to provide CO₂ concentrations no higher than 0.06%. Light is also needed for proper formation of the mushroom, at least six hours of continuous light from a source which gives 500-1000 lux (or 60 lux at the fruiting surface). Wavelengths in the range of 400-700 nanometers are required. The initial pins will appear in 3-4 days, but are difficult to see at this point.

Maturity of the Pins

The following factors are important for the development of the oyster mushroom: (a) CO₂ concentration; (b) relative humidity; (c) substrate and air temperature; and (d) light. The CO₂ concentration during maturation should not be greater than 0.06%. A high rate of ventilation is required. For the first flush, 7-12 m³ of air per m² of production surface per hr is generally necessary. Each successive flush requires about one-third less ventilation. The relative humidity during the cropping period should be maintained at 90-95%. Temperatures for the winter types should be kept at 12-14°C during the picking period and for the summer types at 18-25°C. If temperatures deviate from the prescribed format, many little pins will die and the shape as well as the weight of the fruiting body will be abnormal. The light requirements for pinning should be maintained throughout the cropping periods.

The first flush of mushrooms is ready for harvest 10-14 days after the cold and light treatments begin. Subsequently, 3-5 flushes are produced at 10-15-day intervals. Yield varies between 100-150 kg of mushroom per wet tonne of substrate.

Spore Formation

Oyster mushrooms produce very many small spores. Typical hay fever reactions may develop within minutes by



Figure 43. Harvesting oyster mushrooms while wearing a protective mask



Figure 44. Packaging of oyster mushrooms for market

those individuals sensitive to other airborne allergens. Many people can be or become allergic to breathing these spores. Symptoms resemble those of influenza: exhaustion, dizziness, headache, cough, chills, shooting pains and fever up to 39°C. To decrease the spore problem a few measures can be taken. (1) The culture of sporeless or very low spore varieties is promising. The first commercially developed strains were marketed by Somycel in 1984. (2) A mouth and nose mask may be worn during all activities in the oyster production rooms (Figure 43). (3) Before entering the harvesting rooms, exchange as much fresh air into the room via maximum or additional ventilator. A ventilation with a capacity of 20,000 m³ per 10 tonnes of substrate has been recommended. (4) Maintain a high relative humidity of 90-95%. (5) Filter the output and circulation air of each room. (6) Only pick the mushrooms in the production room.

Sorting, grading and preparing the packages should be done elsewhere (Figure 44).

Research on the oyster and shiitake mushrooms, as well as the buttons, is being conducted at the Horticultural Research Institute of Ontario, Vineland Station.

Although the oyster and shiitake mushroom are produced on a limited scale in Ontario, the size of the industry is expected to grow rapidly once more knowledge is gained on their culture and as the market expands.

The future for the Canadian mushroom industry is an optimistic one. Its steady expansion has made it a valuable vegetable crop, with the demand for mushrooms dramatically exceeding the domestic production. The industry's strength has been its ability to meet the challenges of production and to adapt changes in technology to a specialized cultivation system. This flexibility and determination to succeed set the stage for a bright future for mushroom growing in Canada.

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